Chapter 2

Geology

2 Geology

2.1 Overview of the geology of the Rift Valley Lakes Basin

2.1.1 Location, access and physiography

a. Location and access

The study area is located about 190 km south of the capital Addis Ababa. It is bounded by the limits of 37^{0}00' – 39^{0}30' east longitude and 5^{0}00' – 8^{0}30' north latitude. The area is topographically characterized by the depression zone with steep marginal faults along its edges. The study area is an independent basin, therefore it is called **Rift Valley Lakes Basin (**hereafter RVLB**)**.

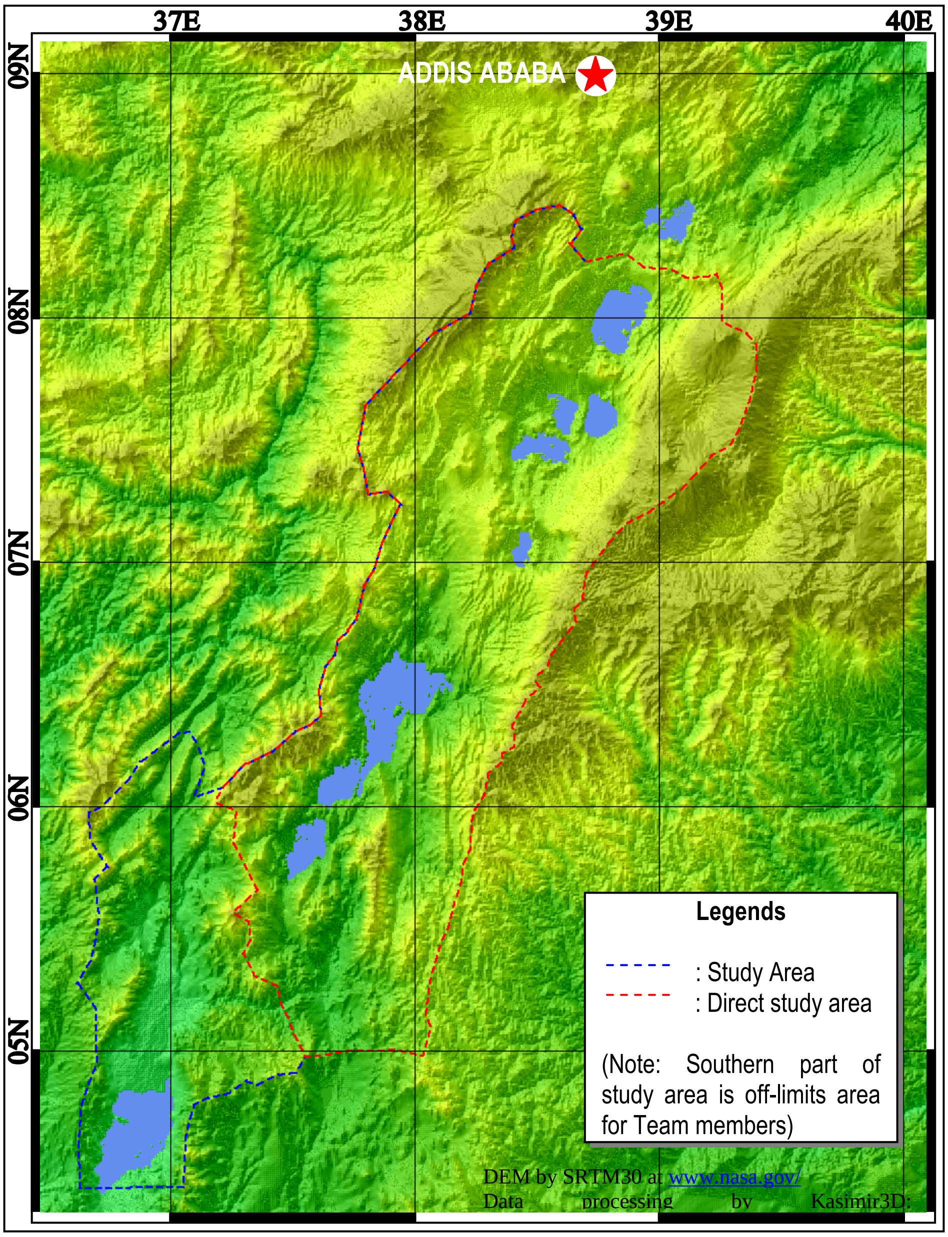

Figure 2.1: Topographic Map of the Study Area

b. **Physiography**

The study area belongs to **African Rift.** The African Rift originates from Aden Junction (see Figure 2.2) and continues in the direction of SW- SSW traverse longitudinally the eastern African countries such as Djibouti, Eritrea, Ethiopia, Kenya, Uganda, and Tanzania.

Generally the valley is characterized by the geological occurrence of active faults, active volcanoes and hot springs, which indicates it is a geothermal area. Geophysical and petrological data show that lithosphere is thinning by intrusion of hot mantle below the valley.

The valley is considered to be a separation boundary of the African Plate. The eastern plate is called Somalian Plate and western is Nubian Plate. The two plates are separating at a speed of 5mm/year (Stamps et. al, 2008).

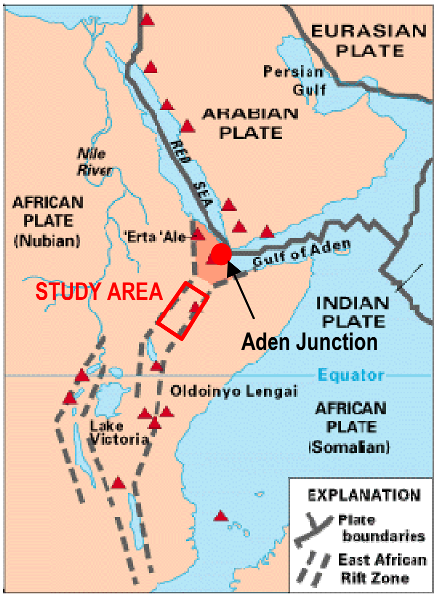

Figure 2.2: Distribution of African Rift Valley

(Source: http://people.dbq.edu/faculty /deasley/ Essays/EastAfricanRift.html)

2.1.2 Regional geological and tectonic setting

a. **Regional geological setting**

The study area belongs to central-southern part of the **Main Ethiopian Rift (MER)**. MER developed over a span from the Oligocene to the Quaternary. During that period, major volcanic episodes are recognized in Oligocene, middle Miocene, late Miocene, early-middle Pleistocene and Holocene (WoldeGabriel et al. 1990). Its abstract is as follows;

The oldest volcanic activities are basalt and rhyolite flows in Oligocene, exposed in and around the rift margins (e.g. Blue Nile gorge), which formed lava plateau in the surrounding area. By middle Miocene, the rift was formed in some parts with containment basaltic flows. In Pliocene, a huge pyroclastic flow covered the northern part of study area. This characteristic pyroclastic flow deposit is currently observed at the depth around 2100m in the basin floor by geothermal well, indicates a minimum of 2km of downthrown in the rift basin since its eruption (WoldeGabriel et al. 1990, WoldeGabriel et al, 2000).

In Pleistocene, Wonji Fault Belt (WFB), which is the main spreading axis of MER, is formed at the rift floor, and floor basalt and rhyolite are erupted along WFB. The volcanic activities are characterized by peralkaline fissure basaltic eruptions and rhyolitic eruptions which make volcanoes and calderas. MER was formed as symmetrical depression zone in this period and many lakes appeared and disappeared by obstruction of volcanic deposit and/or climate change.

b. **Regional tectonic setting**

The MER was created by a complex of NE-SW trending system of tensional faults, cut by a more recent system of NNE-SSW trending faults known as Wonji Fault Belt.

The Rift starts with the Afar Depression in the north, and continues as symmetrical grabens in the center. The continuation of the Rift is distinctive near the border between Ethiopia and Kenya, were small asymmetrical basins are formed instead, and finally the Rift is connected to the Kenya Rift which has a direction of N-S.

The initial stage of MER formation is closely related to that of the Red Sea and Aden Sea. In Mesozoic time, north – central MER was bulged. That is deduced by the existence of thick Mesozoic sediments in Kella horst (North of Butajira) and the Blue Nile gorge.

In Oligocene, large and huge volcanic activity created a lava plateau. In early Miocene, three radial rifts might have been formed in the plateau. After that, two rifts spread open and were downthrown to the sea, which became the Red Sea and Aden Sea. The Other rift, which was not spread well, became the MER.

Such kind of tectonic activity is considered to have occurred in the initial stage when the continent started splitting, and caused by rising of hot plume from the mantle (refer to Figure 2.3).

Structural and stratigraphic relations of volcanic rocks along both rift escarpments of MER indicate a two-stage rift development. The early phase started during late Oligocene – early Miocene and was characterized by a series of alternating and opposed half grabens. The half-grabens evolved into a symmetrical rift during the late Miocene. The area also was characterized by active rifting during Plio-Pleistocene, around 2000m of subsidence was estimated (WoldeGabriel et al, 1990).

The rift floor is nowadays covered by lakes, lacustrine sediments, basalts from fissure eruptions, and silicic tephra from the nearby Quaternary volcanoes. Tectonic movement and volcanic activities in Pleistocene and Holocene are well discussed and summarized by Le Turdu et al. (1999) (refer to Figure 2.4)

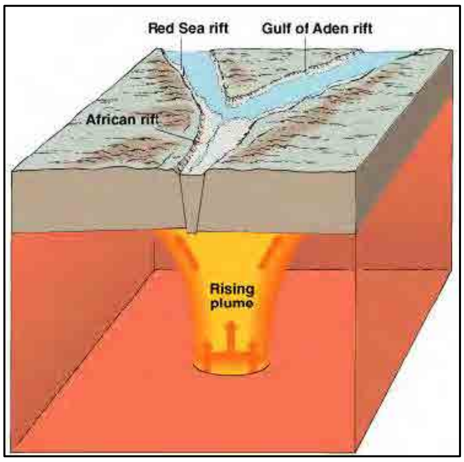

Figure 2.3: Schematic Diagram for Development of Red Sea Rift and Aden Sea Rift, and Failed African Rift (MER)

(Source: http://www3.interscience.wiley.com:8100/legacy/college/levin/0470000201/chap_tutorial/ch07/chapter07-1.html)

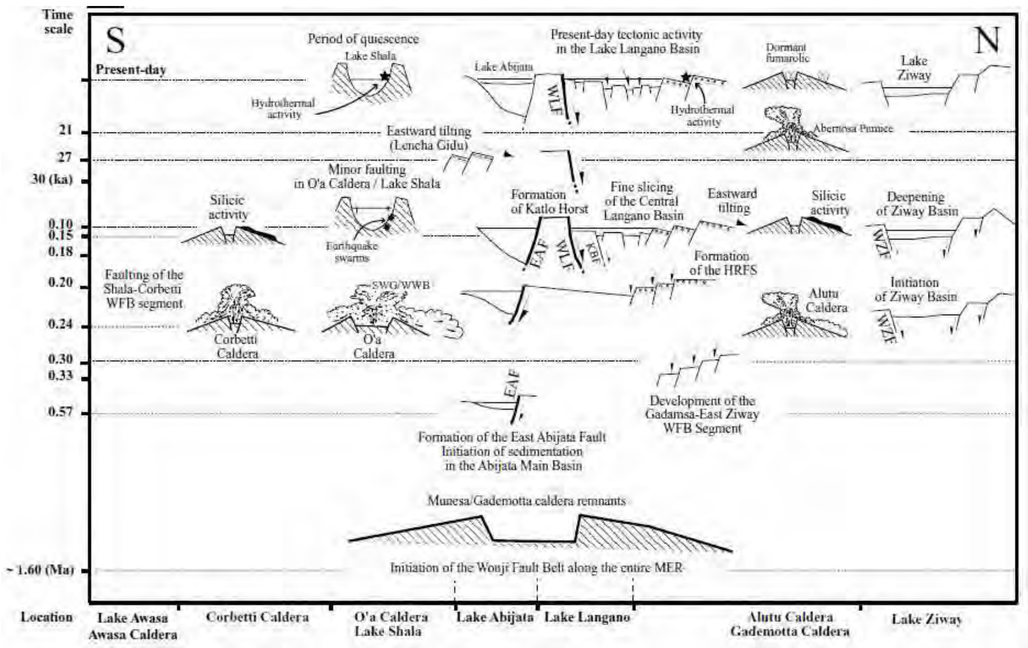

Figure 2.4: Tectonic Movement and Volcanic Activities of Central MER (Le Turdu et al, 1999)

2.2 Geology of RVLB

2.2.1 Previous geological studies and mapping

a. General

Existing geological background data for in and around the Study area were collected prior to the field survey. The lists of collected geological maps for overall and regional geological investigation are as follows.

Most of the maps were made by Geological Survey of Ethiopia (GSE) for the purpose of collecting geological information and researching natural resources in MER.

Table 2.1: Existing Geological Map Covering Study Area.

No	Year	Name	Scale	Author/Publisher
1.	1981	Geological Map of the Ethiopian Rift	1/500,000	Ethiopian Institute of Geological Survey, Ministry of Mines and Energy
2.	1982	Hydrogeology of the Lakes Region, Ethiopia (Lakes Ziway, Langano, Abiyata, Shalla and Awassa)	1/250,000	Ethiopian Institute of Geological Survey, Ministry of Mines and Energy
3.	1983	Geological Map of Omo River Project area	1/500,000	Ethiopian Institute of Geological Surveys, Ministry of Mines and Energy
4.	1986	Geothermal Exploration Project Ethiopian Lakes District Rift, exploitation of Langano-Aluto geothermal resources, Feasibility report	1/125,000	Ministry of Mines and Energy, elc electroconsult, Italy
5.	1994	Geology of Agere Maryam Area	1/250,000	Geological Survey of Ethiopia

				(GSE)
6.	2000	Hydrogeological, geophysical and engineering Geological Investigation of Yabelo Sheet	1/250,000	Geological Survey of Ethiopia (GSE)
7.	2000	Hydrogeological and Engineering Geological Investigation of Chew Bahir Sheet	1/250,000	Geological Survey of Ethiopia (GSE)
8.	2001	Geological Map of the Ziway – Shala Lakes Basin	1/250,000	Dainelli et al., Department of Earth Sciences, University of Florence, Italy
9.	2002	Geothermal resource Exploration in Abaya and Tulu Moye Gedemisa geothermal Prospects, Main Ethiopian Rift	1/50,000	Geological Survey of Ethiopia (GSE)
10.	2003	Hydrogeology and Engineering Geology of Awassa Lake Cachement	1/75,000	Geological Survey of Ethiopia (GSE)
11.	2007	Geology Yabelo MapSheet	1/250,000	Geological Survey of Ethiopia (GSE)
12.	2008	Butajira-Ziway Area Development Study Project, Hydrogeological Map	1/150,000	Ministry of Water Resources, Ethiopian Water Technology Center (EWTEC)
13.	2008	Geological map of Rift Valley Lakes Basin	1/1,500,000	Ministry of Water Resources, Halcrow and GIRDC

b. Summary of review

Geological research of MER has been started since early 1970s. Basic geological investigation was conducted during 1970s to ‘80s in order to explore natural resources such as minerals and geothermal spots.

In 1990s, geology in MER was reviewed and re-investigated by WoldeGabriel et al, (1990), Le Turdu et al. (1999), WoldeGabriel et al, (2000), especially for occurrence and development of MER in the view of “Plate Tectonics”.

From the view point of Quaternary geology, MER is a significant field for the birth and evolution of Hominidae, therefore many geological and archeological studies have been conducted. Some of these studies are detailed stratigraphical and chronological study of tephra at specific archeological sites (e.g. Katoh et al. 2000).

From the aspect of regional development, Halcrow et al. (1991-1992) and Halcrow (2008) conducted regional development master plan in the Study area. They reviewed existing geological and hydrogeological studies and compiled the stratigraphy and geological map of whole RVLB. Hydrogeological studies were conducted in several parts of the study area; EWTEC (2008) in Butajira- Ziway, GSE (2003) and Abiye (2008) in Awasa basin and so on. Tenalem (2008) reviewed and summarized above all hydrogeological studies in RVLB.

Table 2.2: Correlation Chart of Cenozoic Formation in the Study Area

Period/Epoch		Age (Ma)	WoldeGabriel et al. (1990)	EWTEC (2008)	Halcrow (2008)
Quaternary	Holocene	0.0117	Wonji Group	Wonji Group	Wonji Group
Quaternary	Pleistcene	2.58	Wonji Group	Wonji Group	Wonji Group
Neogene	Pliocene	5.33	Chilalo Trachytes Butajira Ignimbrites	Nazareth Group	Chilalo Trachytes Nazret Group/Afar Group
Neogene	Miocene	23.03	Guraghe Basalts Shebele Trachytes	"Ancher Basalts", "Arba Guracha Silicics"	Nazret Group/Afar Group "Ancher Basalts", "Arba Guracha Silicics" A laji Formation
Paleogene	Oligocene	33.9	Kella Basalts		A laji Formation

2.2.2 Review of lithology

a. General

The study area belongs to central-southern part of the **Main Ethiopian Rift (MER)**. MER developed over a span from the Oligocene to the Quaternary. During that period, major volcanic episodes are recognized in Oligocene, middle Miocene, late Miocene, early-middle Pleistocene and Holocene (WoldeGabriel et al. 1990). Its abstract is as follows;

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b. General geology

The general geological conditions of RVLB were explained in this section are divided into the seven areas in the whole area. The geological map (refer to Figure 2.5) based on the field survey of geology and the existing references in RVLB are shown and the correlation chart in the study area is indicated in Table 2.3.

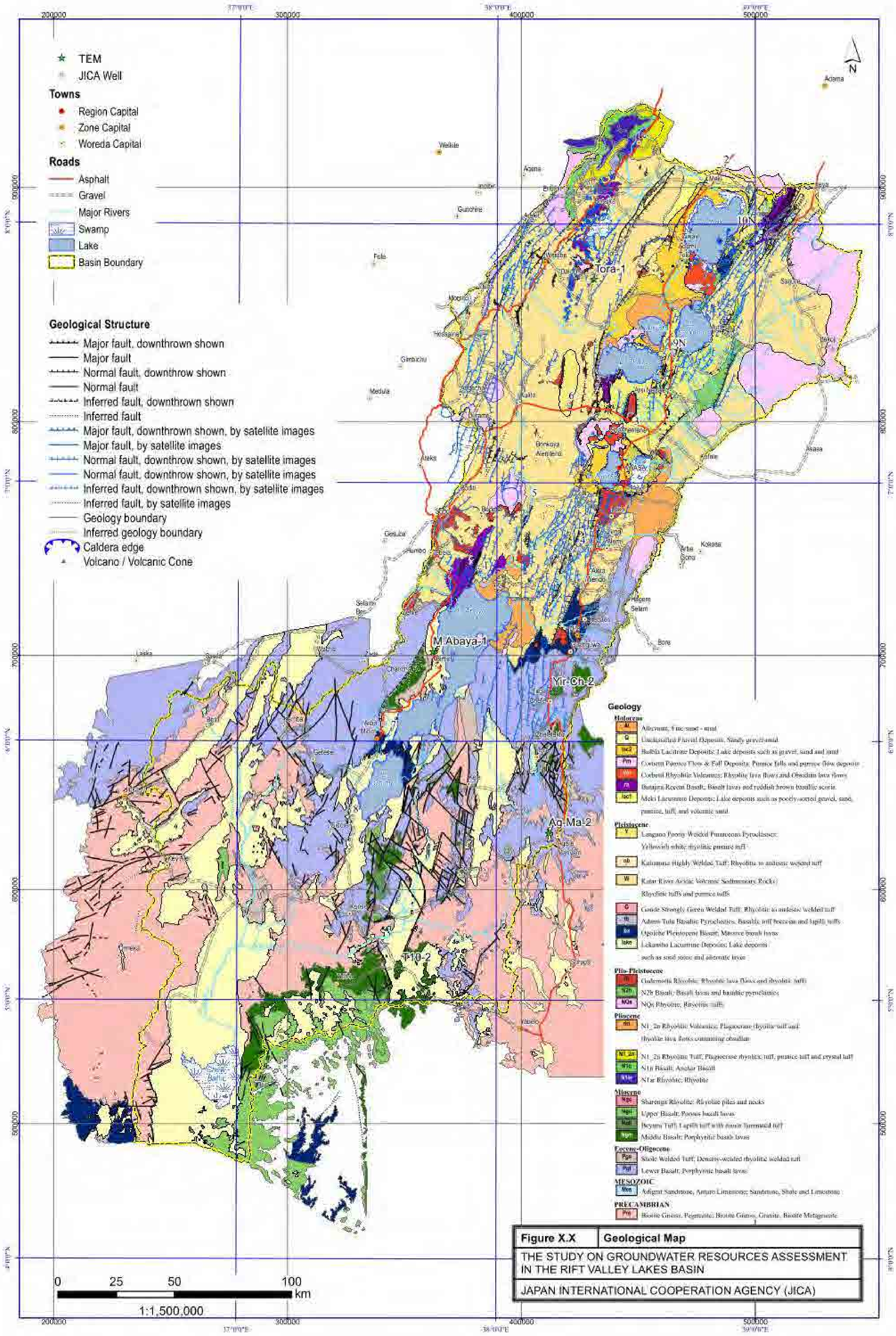


Figure 2.5: Geological Map

Table 2.3: Correlation Chart of the Study Area

Period/ Epoch			Lake Ziway	Lake Abijata, Langano, Shala	Butajira- Hosaina	Lake Awasa	Sodo-Dila-YirgaChafe	Abaya-ArbaMinch	Major Lithology
Cenozoic	Quaternary	Holocene	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Fine sand - mud
			Bulbula lacustrine deposits	Bulbula lacustrine deposits		Shalo lacustrine deposits			Lake deposits such as gravel, sand and mud
			Mt. Aluto volcanics	Alge volcanics	Mt. Ambericho volcanics	Corbetti volcanics	Dugna Fango volcanics		Rhyolite lava flows, pumice falls, pumice flow deposits and Obsidian lava flows
			Deneba Recent Basalt	Awara Recent Basalt	Butajira Recent Basalt	Awasa Recent Basalt	Abaya Recent Basalts		Basalt lavas and reddish brown basaltic scoria
			Meki lacustrine deposits			Wondotika lacustrine deposits			Lake deposits such as poorly-sorted gravel, sand, pumice, tuff, and volcanic sand
		Pleistocene	Asela poorly welded pumiceous pyroclastics	Langano poorly welded pumiceous pyroclastics	Dugba poorly welded pumiceous pyroclastics	Shashemene poorly welded pumiceous pyroclastics		Post-rift Volcanics	Yellowish white rhyolitic pumice tuff
			Kulmusa highly Welded-Tuff	Kuyera highly Welded-Tuff	Koshe highly Welded-Tuff	Mt. Kuwe highly Welded-Tuff	Samero highly Welded-Tuff		Rhyolitic to andestic welded tuff
			Ketar river acidic volcano-sedimentary rocks	Lake Shala acidic volcano-sedimentary rocks	Amecho acidic volcano-sedimentary rocks	Yiega Alem acidic volcano-sedimentary rocks	Yirga Alem acidic volcano-sedimentary rocks		Rhyolitic tuffs and pumice tuffs
			Gonde Strongly Green Welded-Tuff	Bilate river Strongly Green Welded-Tuff	Bilate river Strongly Green Welded-Tuff	Hantate Strongly Green Welded-Tuff	Hantate Strongly Green Welded-Tuff		Rhyolitic to andestic welded tuff
			Adami Tulu basaltic pyroclastics	Shala Senbete basaltic pyroclastics		Abaye ridge basaltic pyroclastics	Donga basaltic pyroclastics		Basaltic tuff breccias and lapilli tuffs
			Ogolche Basalt	Lake Chitu Basalt	Deneba Basalt	Yubo Basalt	Kebado Basalt		Massive basalt lavas
			Lekansho Lake deposits						Lake deposits such as sand stone
	Neogene	Plio-Pleistocene	Gademotta rhyolite	Aje rhyolite	Gademotta rhyolite	Wendo Genet Rhyolite	Hobicha rhyolite	Gocho Rhyolite	Rhyolite lava flows and rhyolitic tuffs
			Bofa Basalt	Lepis Basalt	N2b				Basalt Lavas and pyroclastics
		Pliocene			NQs				Rhyolitic tuffs,Plagioclase rhyolite tuff
			Hangasu Rhyolite	Munesa rhyolite	N1_2n	Wijigra Rhyolite			Rhyolitic tuffs,Plagioclase rhyolite tuff
					N1n				Basalt Lavas and pyroclastics
					N1ar				Rhyolitic tuffs,Plagioclase rhyolite tuff
		Miocene						Sharenga Rhyolite	Rhyolite piles and necks
							Middle Basalt	Middle Basalt	Porous basalt lavas
		Eocene-Oligocene					Shole Ignimbrite	Shole Ignimbrite	Densely-welded rhyolitic welded tuff
							Lower Basalt	Lower Basalt	Porphyritic basalt lavas
Mesozoic					Adigrat Sandstone Antaro Limestone				Sandstone, Shale and Limestone
Pre-Cambrian					Biotite Gneiss, Pegmatite		Biotite Gneiss	Gneiss, Biotite Metagranite	Biotite Gneiss, Granite and Pegmatite

Lake Ziway and its surrounding areas are located in the central MER. The Rift floor is widely covered by Holocene lake deposits. WFB is well developed on the floor and margin of MER in the area, therefore Pliocene – Pleistocene strata are generally observed at the scarps of these faults. Volcanic rocks are thickly deposited at Gademotta and Mt. Aluto, and were named as Gademotta Rhyolite and Mt. Aluto Volcanics in the Study; however, distributions of these volcanics are unclear due to overlying Holocene deposits.

The lowest unit, called Bofa Basalt, is observed only beside the fault scarp which is located at the east of Mt. Aluto. Borehole data of geothermal study indicates that the Bofa Basalt is overlain by Gademotta Rhyolite. Similar kind of rhyolite is observed to the east of Lake Ziway, so some rhyolitic volcanoes may have existed at that time. Ogolche Basalt, Adami Tulu Basaltic Pyroclastics and Kulumusa highly Welded Tuff overlie Gademotta Rhyolite with intercalation of lake sediments.

In Holocene, volcanic activities of rift floor basalts and rhyolite volcanoes along the WFB occurred with the development of lakes and/or swamps.
Late Pliocene (3.6Ma) tuff is observed at a depth of 2100m from Mt.Aluto by geothermal investigation that indicates approximately 2000 m subsidence occurred since Late Pliocene.

Lake Abijata-Langano-Shala and its surrounding areas are located on the basin floor of central part in MER, which composes the flat floor of Lake Ziway area. The basin floor is widely covered by Holocene lacustrine deposits; however, WFB cuts those sediments at some part, and forms step-like topography. Distribution of Lake Abijata and Lake Langano is controlled by such faults. Lake Shalla is a caldera created by a volcanic eruption.

The lowest geological unit in the area is rhyolitic tuff which outcrops at Munesa, located at the escarpment east of Lake Langano. This rhyolitic tuff is known to be distributed extensively in the surrounding area and has 3.17-3.48Ma chronological age by WoldeGabriel et al., 1990, indicates that gigantic volcanic activity occurred in this area at that time (WoldeGabriel et al 1990, Le Turdu et. al, 1999).

Bilate River Strongly Welded Tuff and upper units are well observed on the caldera wall of Lake Shala. Kuyera Highly Welded Medium Tuff and Langano Poorly Welded Pumiceous Pyroclastics are widely distributed at horsts between Lake Langano and Lake Abijata, to Shashamene Town.

In Holocene age, volcanic activities of rift floor basalt occurred in the southwest of Lake Shala, and they continued to the south toward WFB. Simultaneously, volcanic activity of rhyolite occurred in the northeast of Lake Shala.

Lake Awasa and its surrounding areas is a caldera basin which is surrounded by steep caldera wall. Late Miocene to Pleistocene volcanic rocks are exposed toward the wall. Holocene sediments are distributed on the floor of the caldera.

The lowest unit is Wendo Genet Rhyolite, which is thickly exposed at the foot of caldera wall, may have erupted from Awasa caldera. Western and southern part of caldera, Wendo Genet Rhyolite is overlain by Abaye ridge basaltic pyroclastics. Welded tuffs which are correlated to the other two areas are rarely exposed on the caldera wall.

Corbetti Volcano is prominent in Holocene volcanic activity. This volcano was active around 20,000 years ago and nowadays fumalore is found at the top.

The width of RVLB becomes narrower from the north direction and the sedimentary basin of valley is shallow and small scale relatively in Sodo-Dila-YirgaChafe and its surrounding area. Neogene Basalt erupted during early development of RVLB and older deposits than that are distributed in this area. And also the basement rocks of Pre-cambrian period and Tertiary volcanic rocks can be recognized in the RVLB.

Butajira-Hosaina and its surrounding area are located in the west area of RVLB, and are characterized by topography bounded by steps of continuous faults in direction of NNE-SSW series from valley floor to escarpment of RVLB. The Tertiary deposits mainly chop out at escarpment and the strata are distributed on the valley floor continuously contacted by the above faults.

Pre-Cambrian to Neogene formations are mainly distributed and deformed by N-S faults in Abaya – Arba Minch and its surrounding area. Pliocene to Pliestocene units are slightly distributed on the small basins which originated from the N-S faults in the above formations. Pliocene to Pliestocene units are composed of distinctive volcanic deposits, lake deposits, colluvium and alluvium. Basins are relatively smaller than northern part of RVLB and developed weakly.

Pre-Cambrian basement rock is widely observed and forms gentle hills in Hagare Mariam – Yabelo and its surrounding area. N-S and NW-SE fault system is developed in the western part, which forms steep ridges. Neogene and Quaternary strata are mainly composed of loose sand and mud deposited in weakly-developed basins.

2.3 Geological units

The stratigraphy in the study area is established based on the correlation with the strata of each area. The geological units are described as follows in the Table 2.4;

2.3.1 Precambrian, Paleozoic

Biotite gneiss and schists are generally reported in the Study area. At Kella in Butajira, altered biotite gneiss is intruded by silicic pegmatites (WoldeGabriel et al. 1990, EWTEC 2008). At Amaro ridge in the southeast of Lake Abaya, biotite gneiss forms horst. Gneiss and related rock are distributed along N-S trend ridge at Haro Ridge in the east of Lake Abaya and Lake Chamo, Mt. Gedere and Getira Ridge in the east of Lake Chamo, cliff at Zaga in the west of Lake Chamo, Gerese Zema in the south of Zaga. Biotite metagranite is distributed at Mt. Walla (GSE, 1994 and GSE, 1983: Geological Map of Omo River Project area).Their lithology is mostly the same as other basement crystalline rocks and formed in Precambrian age of 960- 370Ma (WoldeGabriel et al. 1990).

2.3.2 Mesozoic sedimentary rocks

Sandstone, shale and limestone (maal) overlies biotite gneiss by unconformity at Kella in Butajira. Sandstone is quartz- arenite (EWTEC, 2008) and 150-200m thick (WoldeGabriel et al. 1990). Thickness of shale and limestone overlying sandstone are 30m and 20m. These strata were deposited in the Jurassic Period (WoldeGabriel et al. 1990). Cretaceous 1000m-thick sandstone is abundant in other areas in Ethiopia, however this sandstone is absent at Kella, and Oligocene basalt overlies the Jurassic sediments by unconformity.

Table 2.4: Stratigraphy in the Study Area

Period/Epoch			Stratigraphy	Name of strata	Name of Formation	Major Lithology	Distribution
Cenozoic	Quaternary	Holocene	Al	Alluvium,	Alluvium	Fine sand - mud	distributed in entire RVLB
			Q	Unclassified Fluvial Deposits	Quaternary sediments	Sandy gravel-mud	distributed in entire RVLB
			lac 2	Bulbula Lacustrine Deposits	Bulbula lacustrine deposits, Shalo lacustrine deposits	Lake deposits such as gravel, sand and mud	locally distributed in northern part of RVLB and surrounding Lake Awassa area
			Pm / volcan	Corbetti Pumice Flow & Fall Deposits/ Corbetti Rhyolitic Volcanics	Mt. Aluto volcanics, Alge volcanics, Mt. Ambericho volcanics, Corbetti volcanics, Dugna Fango volcanics	Rhyolite lava flows, pumice falls, pumice flow deposits and Obsidian lava flows	locally distributed from Ziway to Abaya- Arba Minch area
			rb	Butajira Recent Basalt	Deneba Recent Basalt, Awara Recent Basalt, Butajira Recent Basalt, Awasa Recent Basalt, Abaya Recent Basalts	Basalt lavas and reddish brown basaltic scoria	zonally distributed on the floor of entire RVLB excluding southern part
			lac 1	Meki Lacustrine Deposits	Meki lacustrine deposits, Wondotika lacustrine deposits	Lake deposits such as poorly-sorted gravel, sand, pumice, tuff, and volcanic sand	locally distributed surrounding Lake Ziway and Lake Awassa area
		Pleistocene	Y	Langano Poorly Welded Pumiceous Pyroclastics	Asela poorly welded pumiceous pyroclastics, Langano poorly welded pumiceous pyroclastics, Dugba poorly welded pumiceous pyroclastics, Shashemene poorly welded pumiceous pyroclastics	Yellowish white rhyolitic pumice tuff	continuously distributed from Ziway to Awassa area
			ob	Kulmusa Highly Welded Tuff	Kulmusa highly Welded-Tuff, Kuyera highly Welded-Tuff, Koshe highly Welded-Tuff, Mt. Kuwe highly Welded-Tuff, Samero highly Welded-Tuff	Rhyolitic to andestic welded tuff	continuously distributed from Ziway to Dila area
			W	Ketar River Acidic Volcanic Sedimentary Rocks	Ketar river acidic volcanic sedimentary rocks, Lake Shala acidic volcanic sedimentary rocks, Amecho acidic volcanic sedimentary rocks, Yiega Alem acidic volcanic sedimentary rocks	Rhyolitic tuffs and pumice tuffs	continuously distributed from Ziway to Dila area
			G	Gonde Strongly Green Welded Tuff	Gonde Strongly Green Welded-Tuff, Bilate river Strongly Green Welded-Tuff, Hantate Strongly Green Welded-Tuff	Rhyolitic to andestic welded tuff	continuously distributed from Ziway to Dila area
			tb	Adami Tulu Basaltic Pyroclastics	Adami Tulu basaltic pyroclastics, Shala Senbete basaltic pyroclastics, Abaye ridge basaltic pyroclastics, Donga basaltic pyroclastics	Basaltic tuff breccias and lapilli tuffs	locally distributed in entire RVLB
			ba	Ogolche Pleistocene Basalt	Ogolche Basalt, Lake Chitu Basalt, Deneba Basalt, Yubo Basalt, Kebado Basalt, (Post-rift Volcanics)	Massive basalt lavas	locally distributed in entire RVLB
			lak	Lekansho Lacustrine Deposits	Lekansho Lake deposits	Lake deposits such as sand stone and alternate layer	locally distributed in Ziway and surrounding area
	Tertiary	Plio-Pleistocene	rh	Gademotta Rhyolite	Gademotta rhyolite, Aje rhyolite, Wendo Genet Rhyolite, Hobicha rhyolite, Gocho Rhyolite	Rhyolite lava flows and rhyolitic tuffs	continuously distributed in entire RVLB
			N2b	N2b Basal	Bofa Basalt、Lepis Basalt	Basalt lavas and basaltic pyroclastics	distributed only in the south of Lake Ziway
			NOs	NQs Rhyolite	NQs	Rhyolitic tuffs	locally distributed in Butajira area
		Pliocene	rht/N1_2n	N1_2n Rhyolitic Volcanics/Rhyolitic Tuff	Munesa rhyolite,Hangasu Rhyolite, Wijigra Rhyolite,N1_2n	Plagiocrase rhyolite tuff	locally distributed in entire RVLB
			N1n	N1n Basalt	N1n	Anchar Basalt	locally distributed in Butajira area
			N1ar	N1ar Rhyolite	N1ar	Rhyolite	locally distributed in Butajira area
		Miocene	Ngs	Sharenga Rhyolite	Sharenga Rhyolite	Rhyolite piles and necks	distributed only in Abaya- Alba Minch and surrounding area
			Ngu	Upper Basalt	Upper Basalt	Porous basalt lavas	continuousely distributed in the south of Dila
			Ngb	Beyana Tuff	Beyana Tuff	Lapilli tuff with minor laminated tuff	continuousely distributed in the south of Dila
			Ngm	Middle Basalt	Middle Basalt	Porphyritic basalt lavas	continuousely distributed in the south of Dila
		Eocene-Origocene	Pgs	Shole Welded Tuff	Shole Ignimbrite	Densely-welded rhyolitic welded tuff	continuousely distributed in the south of Dila
			Pgl	Lower Basalt	Lower Basalt	Porphyritic basalt lavas	continuousely distributed in the south of Dila
Mesozoic			Mes	Adigrat Sandstone, Antaro Limestone	Adigrat Sandstone, Antaro Limestone	Sandstone, Shale and Limestone	locally distributed in Kella, northern part of Butajira
Pre-Cambrian			Pre	Biotite Gneiss, Pegmatite	Biotite Gneiss, Granite, Biotite Metagranite	Biotite Gneiss, Granite, Biotite Metagranite	distributed in Kella, northern part of ButajiraButajira and HagereSelam-Yabelo area

References: (1) Laury and Albritton 1975, (2) Mohr et al. 1980, (3) EIGS-GLE 1985, (4) Woldegabriel et al. 1990, (5) GSE 1994, (6) GSE 2002, (7) EWTEC 2008

2.3.3 Middle Eocene –lower Oligocene

a. Lower basalt

Lithology : Consists of dark gray to blueish gray porous or porphylitic basalt lava. Generally the unit is well weathered so olivine phenocrysts are altered into greenish brown to brown color and plagioclase is visible. The unit is commonly weathered and has onion-like-weathered surface, however fresh basalt is observed at Ocholo, beside the road of Arba Minch – Chenche (Uk-101130-03).

Distribution : The unit is distributed widely at Zefine to Wajifo in the east of Lake Abaya and Lake Chamo, foot of Haro Ridge in the west, Segen in the south, Arba Minch and Konso area.

Thickness : 710m at Mt. Getra in the southwest of Arba Minch, 630m at Mt. Dilo in the east of Lake Chamo

Type locality : Southern foot of Mt. Zede, north of Arba Minch (Uk100217-09)

Relationship with lower unit : The unit widely overlies Pre-Cambrian by unconformity in Agere Maryam area. The unit might overlie Arba Minch felsic tuff in the south of Arba Minch, however details are not clear (GSE 1994).

Correlation : The unit is classified as PNv: Rhyolites, trachytes, ignimbrites with minor tuff and basalt of A laji Formation at type locality, Pv: Aphyric and porphyiritic Basalt and Salic flows covering the whole area in Halcrow (2008), Tb1: Pre-rift Basalts in GSE (2002).

Chronology : 36.7 – 37.9Ma and 37.6 – 44.9Ma (GSE, 1994)


Southern foot of Mt.Zede, north of Arba Minch (Uk-100217-09)

Zela Gutisha, East of Ego (Uk-101130-04)

Chano Dorga (Uk-101130-01)

Figure 2.6: Type Locality and Lithology of Lower Basalt

b. Shole Welded Tuff

Lithology : Consists of light blueish gray to blueish gray rhyolitic dense welded tuff including flattered pumice, dark gray to greenish gray pumiceous medium tuff and greenish brown pumice layer. Blueish gray rhyolitic welded tuff is observed at type locality.

Distribution : Gecho in the northeast of Zefine, BirBir, Mt.Zede in the north of Arba Minch, foot of Haro Ridge in the west of Lake Chamo, Segen in the south and Konso area (GSE, 1994).

Thickness : 36m in Mt. Dilo, east of Lake Chamo (GSE, 1994)

Type locality : Gocho, northeast of Zefine (Uk101118-08)

Relationship with lower unit : The unit overlies Lower Basalt by unconformity at the roadside of Arba Minch – Konso road (Uk-100218-03). The unit also overlies Lower Basalt and underlies Middle Basalt by unconformity at the southern foot of Mt. Zede in the north of Arba Minch.

Correlation : The unit is classified as PNv: Rhyolites, trachytes, ignimbrites with minor tuff and basalt of A laji Formation in Halcrow (2008), Tig: Chewkare Ignimbrite in GSE (2002).

Chronology : 35.5 – 37.0Ma and 37.6 – 33.9Ma (GSE, 1994)

Goche, northeast of Zefine (Uk-101118-08)

Southern Arba Minch (Uk-100218-03)

Doshe, northern Birbir (Uk-100217-5)

Figure 2.7: Type Locality and Lithology of Shole Ignimbrite

2.3.4 Tertiary lower Miocene

a. Middle basalt

Lithology : Consists of dark gray to blueish gray porous or porphylitic basalt lava. Generally the unit is well weathered so olivine phenocrysts are altered into greenish brown to brown color and plagioclase is visible. It is very difficult to identify this unit from Lower Basalt in the area where Shore Ignimbrite is not found.

Distribution : The unit is distributed at Birbir in the south of Lake Abaya, north of Arba Minch and east of Lake Chamo, overlying Shole Ignimbrite.

Thickness : 110m at Mt. Dilo in the east of Lake Chamo (GSE, 1994)

Type locality : Southern foot of Mt. Zede, north of Arba Minch (Uk100217-09)

Relationship with lower unit : The unit overlies Shole Ignimbrite by unconformity at the type locality.

Correlation : The unit is classified as PNv: Rhyolites, trachytes, ignimbrites with minor tuff and basalt of A laji Formation in Halcrow (2008).

Chronology : 12.6Ma, 12.9Ma and 11.1Ma (GSE, 1994)

Mt.Zede, north of Arba Minch (Uk-100217-09)

Figure 2.8: Type Locality and Lithology of Middle Basalt

b. Beyana Tuff

The description of this layer is in reference to the GSE (1994) Geology of the Agere Maryam Area.

c. Upper Basalt

The description of this layer is in reference to the GSE (1994) Geology of the Agere Maryam Area

d. Sharenga Rhyolite

The unit is composed of purplish gray rhyolite lava, distributed as volcanic plugs in the east of Lake Chamo. The plugs have 100m to 1.5km diameter and maximum 250m high. K-Ar age is defined: 13.0Ma (Ebinger et al., 1991). More details are described in GSE (1994).

2.3.5 Tertiary Pliocene

a. N1ar Rhyolite

Lithology : Consists of blueish gray fine to medium rhyolitic tuff. The feldspar group color change to brown for the weathering in general.

Distribution : Bui, north of Butajira to Tiya

Thickness : More than 200m at the type locality

Type locality : West Bui (Uk110520-04)

Relationship with lower unit : The unit overlies the Pre-Cambrian and Mesozoic sedimentary rocks in west Kella (EWTEC,2008)

Correlation : EWTEC (2008) and Halcrow (2008) are correlated with Arba Guracha silicics (N1ar) of the Nazreth Group at the type locality.

West Bui（Uk110520-04）

Figure 2.9: The Photo of Niar Lithology

b. N1n Basalt

Lithology : Consists of dark blue and gray fine basalt. The feldspar group color is generally changed to brown for by weathering in general.

Distribution : Bui, north of Butajira to Tiya

Thickness : More than 300m at the type locality

Type locality : West Bui (Uk110520-03)

Relationship with lower unit : The unit overlies the gentle slope which consiste of Niar clearly at type locality area topographically, however the detail relationship is not clear.

Correlation : EWTEC (2008) and Halcrow (2008) are correlated with Arba Guracha silicics (N1n) of the Nazreth Group at the type locality.

West Bui(Uk110420-05)

Figure 2.10: Photo of N1n Type Lithology

c. N1_2n Rhyolite

This member is named as N1_2n Rhyolite based on the correlation with Nazreth Group. This member consists of the below strata.

N1_2n

Lithology : Consists of dark bluish gray fine to medium rhyolitic tuff, pumice tuff, crystal tuff. The feldspar group color is generally changed to brown by weathering in general. The pumice tuff is distributed from Bui to Suten and the coarse crystal tuff is distributed at the mountain area of west Kella.

Distribution : Bui, north of Butajira to Tiya

Thickness : More than 200m at the type locality

Type locality : West Bui (Uk110520-08)

Relationship with lower unit : The unit overlies the N1n with unconformity topographically at the type locality and river side of Suten, however the detail relationship is not clear.

Correlation : EWTEC (2008) and Halcrow (2008) are correlated with Stratoid Sillicics （N1_2n） of the Nazreth Group at the type locality. And the crystal tuff distributed at Kella and its surrounding area is correlated with Munessa Crystal Tuff as the Crystal Tuff.

Chronology : 3.6 to 4.1Ma (No.5-9), from crystal tuff at Bui and 2.59-2.67Ma (No.10, 11). as K-Ar age from tuff upper part of crystal tuff by WoldeGabriel et al., 1990. This crystal tuff has similar age with the 3.51-3.53±0.01Ma（No.34,35）by K-Ar age of the tuff distributed at Munesa area, so this crystal tuff is classified as Munesa Crystal included the lithology.

Munesa Rhyolite

Lithology : Consists of blueish gray to light gray rhyolitic fine to medium tuff and obsidian-containing rhyolite. Crystal tuff was found with underlying obsidian-containing rhyolite lava of the same unit.

Distribution : Surrounding Mt. Ate in the west of Munesa

Thickness : More than 300m (WoldeGabriel et al., 1990)

Type locality : Mt. Ate in the west of Munesa (Uk-101216-05)

Relationship with lower unit : Considered as the lowest unit in the area

Correlation : The unit is classified as Stratoid Silicics in Nazareth Group (N1-2n, stratoid silicics, ignimbrites, unwelded tuffs, ash-flows, rhyolites and trachytes）in Halcrow (2008) and T τ : Volcanites of the Plateux in Dainelli et al. (2001).

Chronology : 3.19 to 3.4±0.1Ma K-Ar age from tuff and 2.95±0.3Ma K-Ar Age from obsidian in Munesa by WoldeGabriel et al., 1990 (No. 39, 40 and 36).

Mt.Ate (Ate Zera Yaikob), western part of Munesa (Uk-101216-05)

Figure 2.11: Type Locality and Lithology of Munesa Rhyolite

Hangasu Rhyolite

Lithology : Consists of blueish gray to light gray rhyolitic medium tuff and white-light yellow pumice bearing tuff which has poor density.

Distribution : Washe Dante Ridge in Southeastern Part of Lake Ziway, Hangasu, Doya, Mt. Goria in Northeastern part of Ogolcho, hilly area at the foot of Mt. Amecho and Chufa in southern part of Ogolcho.

Thickness : 15m+ at type locality

Type locality : South in Weshe Dante Ridge, southeastern part of Lake Ziway (Uk-101213-04)

Relationship with lower unit : Considered as the lowest unit in the area.

Correlation : The unit is classified as Stratoid Silicics of Nazareth Group (N1-2n, stratoid silicics, ignimbrites, unwelded tuffs, ash-flows, rhyolites and trachytes) in Halcrow (2008), and Pρ: Rift Floor Ignimbrite in Dainelli et al. (2001)

Mt.Amecho, northeastern part of Ogolcho (Uk-101215-06)

Figure 2.12: Type Locality and Lithology of Hangasu Rhyorite

Wijigra rhyolite

Lithology : Consists mainly of white to blueish gray rhyolite tuff containing white pumice.

At type locality, rhyolite tuff contains rhyolitic and basaltic fragments and matrix contains yellowish green pearlitic pumice. This unit produces large quantity of water, which is observed at springs and hot springs in eastern to southeastern part of Wend Genet. This unit is separated from Wendo Genet rhyolite, the upper unit, by lithological character and distributions described in GSE (1986).

Distribution : Wijigra – Wendo Genet, eastern part of Awasa area. The unit is exposed at the eastern caldera wall at heights of between 2200m – 2500m.

Thickness : More than 300m at the type locality

Type locality : Outcrop beside the way from Wendo Genet to Guguma, around 2000m in height (Uk-100607-07)

Relationship with lower unit : The unit is considered as the lowest unit in this area.

Correlation : N1_2n and NQs of Nazareth Group in Halcrow (2008) and GSE (2003)

Uk-100607-07 beside Guguma road, Wendo Ganet

Figure 2.13: Type Locality and Lithology of Wijigra rhyolite

2.3.6 Plio-Pleistocene

a. NQs Rhyolite

The description of this layer is in reference to EWTEC (2008).

b. N2b Basalt

This member is named as N2b Basalt based on the correlation with Nazreth Group. This member consists of the below strata.

Bofa Basalt

Lithology : Consists of basalt lavas and basaltic pyroclastics.

Distribution : Eastern Part of Mt.Aluto, the south of Lake Ziway

Thickness : Around 700m at the center of Mt. Aluto (from borehole data by GSE, 1986)

Relationship with lower unit : The unit overlies Hangasu Rhyolite by unconformity at

Southeast of Ziway

Correlation : The unit is classified as Bofa Basalts in Halcrow (2008), and Pρ: Rift Floor Ignimbrite in Dainelli et al. (2001)

Detailed investigation was not done in the Study and distribution is followed by GSE (1986).

Lepis Basalt

Lithology : Consists mainly of dark gray to black massive basalt. At type locality, an approximately 30m high waterfall is formed by basalt lava, and basalt lava is distributed downward in Lepis River with scoriaceous surface (Uk-100308-03).

Distribution : Upward of Lapis River in the east of Arsi Negere, flat plain at the shoulder surrounding Munesa.

Thickness : More than 30m at type locality

Type locality : Adami Tulu, south of Lake Ziway (Uk-100209-02)

Relationship with lower unit : The unit overlies Munesa rhyolite by unconformity. The relationship between Aje ryolite might be unconformity due to distribution of the unit.

Correlation : The unit is classified as NQs: Nazareth Group and Dino Formation at type locality and QWbp: Basalts of the rift floor at Shala Senbete in Halcrow (2008), and T τ : Volcanic of the plateaux at Munesa and Qfl: Wonji-Butajira basaltic lava flow at Shala Senbete in Dainelli et al. (2001).

Chronology : 2.54 ±0.01Ma K-Ar age from this layer in Munesa by WoldeGabriel et al., 1990 (No. 38).


Uk-100323-06 Lepis Fall


Uk-100308-03

Figure 2.14: Type Locality and Lithology of Lepis Basalt

c. Gademotta Rhyolite

The members below distributed in each area are represented by this name.

Lithology : Consists mainly of white to blueish gray rhyolite lava flows and tuffs, white pumice and hard tuffs including obsidians. Blueish gray rhyolite lava flow with columnar joint is observed at type locality. This unit is overlain by Adami Tulu Basaltic Pyroclastics (described later) by unconformity near the type locality (Uk-100518-05). The unit is silicified by the heat from the overlying unit along the unconformity boundary. Southwestern foot of Mt. Bericha in Ogolche (Uk-100518-05), rhyolite lava is observed to have developed platy joints and obsidians forming along chilled margin, partially auto-brecciated in subaqueos condition. The mountain of 2800m to 3000m above see level is continued in direction of NNE is consisted by these strata at Bilalu-Kebut-Aratit of western area of RVLB. The rhyolitic lava developed platy joint with obsidian is distributed at the north of Bilalu (Uk-101208-03) along the road to Bilalu-Aratit. The falls are formed in the west side of fault by the step faults at the west of Werabey (Uk-101207-04&06).

Distribution : Gademotta Caldera, the west of Lake Ziway and Ogolche area, the north of Lake Ziway and highland of west side of RVLB, Mt. Gafato (2414m in height), Mt. Balchi (2215m in height) at Dolocha, and along river of west of Werabey.

Thickness : Around 150m in the type locality

Type locality : Quarry site in Gademotta, 5km west of Ziway Town (Ho-100423-01)

Relationship with lower unit : The relationship is not observed on the surface, but observed in borehole, the unit is underlain by Bofa Basalt (GSE, 1986). Due to intercalation of thin sediment layers between those units, the boundary is considered as unconformity.

Correlation : Volcanic rocks in Gademotta caldera is classified as Qwa: Gademotta Central Volcanic Complex in Halcrow (2008) and Pα: Gademotta-Balci alkaline and peralkaline rhyolitic lava flows and domes in rocks in Dainelli et al. (2001). Volcanic rocks in Ogolche are classified as Ql in Halcrow (2008) and Qω: Alutu-Bericho rhyolitic lava flows, unwelded pumice fall and pantelleritic obsidian flow in Dainelli et al. (2001). Both are classified as Qdi: Dino formation in EWTEC (2008)


Gademotta Quarry Site (Ho-100423-01)


Unconformity boundary in Gademotta (Uk-100630-01)

Figure 2.15: Type Locality and Lithology of Gademotta Rhyolite

Aje Rhyolite

Lithology : Consists of white to blueish gray rhyolitic compacted tuff which contains white pumice and rhyolitic lava fragments of approx. 1cm. Near type locality in Aje, gray rhyolitic tuff with white pumices is observed. The unit observed from Bura in north of Aje to western side of Lake Shala, rhyolitic tuff containing many obsidian fragments is observed and forms a 12m high cliff. The same lithology is observed in Mt. Kulisa (Uk-100622-04), and Heregdina (Uk100622-04).

Distribution : N-S distribution in Bura, east of Aje, and some hills in Aje. The unit is also observed at the bottom of valley in the west of Aje. The unit is also found at western side to northwestern side of Lake Shala.

Thickness : More than 120m in the type locality

Type locality : Quarry site located in the northeast of Aje (Uk-100624-13)

Relationship with lower unit : Uncertain

Correlation : The unit is classified as Qwa: Gademotta Central Volcanic Complex and Qdi: Dino Formation in Halcrow (2008) and Pρ : Rift floor ignimbrite in Dainelli et al. (2001).


Uk-100624-13 Aje


Uk-100628-02

Figure 2.16: Type Locality and Lithology of Aje Rhyolite

Wendo Genet rhyolite

Lithology : Consists of white to blueish gray rhyolitic compacted tuff which contains white pumice and rhyolitic lava fragments of approx. 1cm. At the quarry site in the southern side of Lake Awasa (Uk-100226-01), the unit is divided by three lithological facies; from the lowest, dark gray obsidian-bearing rhyolite lava (th.7m+), light gray to light brown rhyolitic tuff containing white pumice (th.20m) and blueish gray massive rhyolitic tuff. At the northern wall of Lake Cheleleka, grassy rhyolite containing obsidian forms columnar joint (Uk-100329-09). At Boricha Ridge, southward of Awasa (Uk-100213-01), fault (N22^{0}E76^{0}E) associated 5m-thick shear zone is observed at rhyolite lava.

Distribution : Widely distributed in Wendo Genet - southern side of Lake Awasa – Morocho. Sparsely distributed at the southwestern side of Awasa and caldera wall of Corbetti volcano.

Thickness : More than 120m at the type locality, more than 300m at the north of Lake Cheleleka.

Type locality : Quarry site located at the southern side of Lake Awasa (Uk-100226-01)

Relationship with lower unit : The unit may overlie Langano poorly welded tuff, however the boundary was uncertain.

Correlation : The unit is classified as N1_2n of Nazareth Group and Qwa in Halcrow (2008), Qwt1, Qwt2 of Dino Formation and Qdi, Qwpu in GSE (2003).

Chronology : 1.10 to 1.85My K-Ar age from the north of Wendo Genet and 2.49±0.1My K-Ar Age from Boricha Ridge by WoldeGabriel et al. (1990)

Ho-100508-1 Roadside outcrop in Wendo Genet

Figure 2.17: Type Locality and Lithology of Wendo Genet rhyolite

Hobicha Rhyolite

Lithology : Consists of white to bluish brown rhyolitic tuff, white pumice, and hard tuff with rock chips of rhyolite (about ϕ1cm). The white pumice and brown rhyolitic tuff with obsidian are observed at type locality. The bluish brown tuff wth pumice is distributed at quarry site (Uk-101123-01） of south Sodo.

Distribution : Sodo and its surrounding area and Hobicha caldera widely in the west, east Dila along the fault of east.

Thickness : 100m+ at type locality

Type locality : Hobicha (Uk-101116-04) at east Sodo

Relationship with lower unit: Unclear

Correlation : This layer correlates with Qwa of Central Volcanic Complex (Halcrow, 2008). On the other hand, this layer corresponds to Qrl (Abaya Rhyolites) (GSE, 2002 Geothermal Resource Exploration in the Abaya and Tulu Moye-Gedemsa Geothermal Prospects, Main Ethiopian Rift). This layer distributed at Dugne Fango and its surrounding area correlates with Qr2 （Dugna Fango Rhyolites） as Quaternary.

Chronology : 1.57Ma (EIGS-GEP, 1981) from rhyolite at Obicha (Hobicha) (GSE, 2002 Geothermal Resource Exploration in the Abaya and Tulu Moye-Gedemsa Geothermal Prospects, Main Ethiopian Rift)

Hobicha (Uk-101116-04)

Wanche Ridge (Uk-101116-03)

Figure 2.18: Type Locality and Lithology of Hobicha Rhyolite

Gocho Rhyolite

Lithology : Consists of white to blueish gray rhyolitic compacted tuff which contains white pumice and rhyolitic lava fragments of approx. 1 cm. Gray rhyolitic tuff is observed including white pumice in type locality.

Distribution : Gocho, northeast of Zefine

Thickness : More than 60m in the type locality

Type locality : Gocho, northeast of Zefine (Uk101118-09)

Relationship with lower unit : The unit overlies a plain which consists of Lower Basalt and Shole Ignimbrite at Gocho. In Mesa, the unit overlies a plain where Middle basalt is distributed. Relationship is unclear.

Correlation : The unit is classified as NQs: Undifferntiated of Nazareth Group and Dino Formation in Halcrow (2008)

Gocho, northeast of Zefine (Uk-101118-09)

Figure 2.19: Type Locality and Lithology of Gocho Rhyolite

2.3.7 Quaternary Pleistocene

a. Lekansho Lake deposits

Lithology : Consists mainly of dark brown to dark gray alternation of mudstone and fine sandstone containing poorly-bubbled pumice.

Distribution : Distributed only in the surrounding area of Sendicho Kebele, southern side of Lake Ziway. The unit consists of terraces whose height is 3-5m above the alluvial plain.

Thickness : Around 5m at type locality

Type locality : Sendicho Kebele, southern side of Lake Ziway (Uk-100210-03)

Relationship with lower unit : The unit is probably underlain by Gademotta Rhyolite, however the boundary was not found.

Correlation : The area is classified as Qwh: Basalts of the floor in Halcrow (2008), Qu: Undifferentiated colluvial- alluvial gravel, sand, silt and pyroclastics in Dainelli et al. (2001) and QwPu: Pumice and unwelded tuffs in EWTEC (2008).

Sedicho Kebele (Uk-100210-03)

Figure 2.20: Type Locality and Lithology of Lekansho Lake Deposits

b. (Pleistocene) Basalt

The strata correlated in each area are unified by this member.

Ogolche Basalt

Lithology : Consists mainly of dark gray to black massive basalt – basaltic andesite lavas. Dark gray dense basalt lava is distributed in Hangasu (Uk-101213-05), where Katar River Acidic volcano sedimentary rocks overlie this unit by unconformity. Hard basalt lava is distributed along the river with scoriaceous surface at Adami Tulu (Uk-100210-03). Basaltic andesite lava is observed at the hill located in southwest of Adami Tulu (Uk-100210-04).

Distribution : Southeast to east of Lake Ziway, Ogorche in the north of Lake Ziway, Sendicho Kebele and Adami Tulu in the south of Lake Ziway

Thickness : More than 3m at type locality, more than 30m in southwest of Adami Tulu

Type locality : Hangasu, east of Lake Ziway (Uk-101213-05)

Relationship with lower unit : The unit forms a terrace which is higher than that of underlain Lekansho Lake deposits, considered as unconformity. In Ogolche, Olivine-bearing basalt lava of this unit overlies yellowish-brown pumice layer by unconformity. The unit also overlies Hangasu Rhyolite by unconformity at the south of Washe Darta Ridge.

Correlation : The unit is classified as Qwh: Basalts of the floor in Halcrow (2008), Qu: Undifferentiated colluvial- alluvial gravel, sand, silt and pyroclastics in Dainelli et al. (2001).

Uk-100518-08 Ogolche

Uk-100210-04

Figure 2.21: Type Locality and Lithology of Ogolche Basalt

Lake Chitu Basalt

Lithology : Consists mainly of dark gray to black massive basalt. In the north of Awara(Type locality （Uk-100309-5）), basalt lava contains olivine phenocryst with scoreaceous surface, has columnar joint and continues to the direction of N-S by forming a 6 to 8m high cliff.

Distribution : A ridge extends toward N-S in the north of Shala Senbete

Thickness : More than 10m at type locality

Type locality : The north of Awara (Uk-100309-5)

Relationship with lower unit : This unit is overlain by Shala Senbete Basaltic Pyroclastics in the north of Shala Senbete (Uk100309-05), however the boundary is unclear.

Correlation : Nazareth Group and Dino Formation at type locality and QWbp: Basalts of the rift floor at Shala Senbete in Halcrow (2008), and T τ : Volcanic of the plateaux at Munesa and Qfl: Wonji-Butajira basaltic lava flow at Shala Senbete in Dainelli et al. (2001).

Uk-100602-04 Lake Chitu | Uk-100309-05

Figure 2.22: Type Locality and Lithology of Lake Chitu Basalt

Deneba Basalt

Lithology : Basalt lava and pyroclastic rocks

Distribution : Eastern area of Dosha located 20km east of Hosaina. The area that the mountain is continued in the direction of NNW from Deneba changes into the direction of NNE at Ambericho (2323m hieght)

Thickness : Unclear

Type locality : East of Deneba（Uk-101206-04）

Relationship with lower unit : These strata are the lowest layer in distributed area and are underlaid by Amecho acidic volcano sedimentary rocks by unconformity at type locality.

Correlation : These strata are correlated with Stratoid Basalts of Afar（mildly subalkalines basalts) of Nazareth Group (GSE, 1981), and Qdi (Halcrow, 2008).

Deneba(Uk-101206-04) | Deneba(Uk-101206-04)

Figure 2.23: Type Locality and Lithology of Deneba Basalt

Yubo basalt

Lithology : Consists of dark gray to black massive basalt with scoriaceous surface. At the ridge south of Yubo, the unit forms a continuous cliff 15-20m in height.

Distribution : Small distribution in Yubo, southeastern part of Awasa.

Thickness : More than 30m at type locality

Type locality : Southward of Yubo, around 1900m in height (Uk-100608-01)

Relationship with lower unit : The unit may overlie Wendo Genet rhyolite, however the boundary was not found. Unconformity boundary is considered based on the distribution of the unit.

Correlation : The unit is classified as NQs of Nazareth Formation/Dino Formation in Halcrow (2008), and Qwb of Dino Formation in GSE (2003).

Chronology : 1.10 to 1.85My K-Ar age from the north of Wendo Genet and 2.49±0.1My K-Ar Age from Boricha Ridge by WoldeGabriel et al. (1990)

Uk-100608-01 Yubo

Figure 2.24: Type Locality and Lithology of Yubo basalt

Kebado Basalt

Lithology : Dark brown to black massive basalt lava. This layer is strongly weathered with onion structure and is characterized by plagioclase like strip of paper at Dila on the east side. This layer forms the hilly area from Dila to Kebado and Chko and its surrounding area. As this layer is strongly weathered, it is very difficult to recognize as Lower and Middle Basalts. Therefore, the basalt which forms one step lower hilly area is recognized as the Quaternary basalt comparing with the Tertiary basalt which forms the highland. The porous and joint developed in this layer is recognized along the Bilate River at Dimtu Village in the central area. The basalt layer which correlates with these strata below pumice flow deposits is verified at 66m to 82m in depth at B-No5 drilling point.

Distribution : west Dila, from Dila to Kebado and Chuko and its surrounding area (forms the hilly area), along the Riv. Bilate at Dimtu in the central area.

Thickness : 20m+ at type locality

Type locality : Riv. Bonkoka quarry site (Uk-101125-6) at west of Kebado

Relationship with lower unit: This layer overlies Hobicha Rhyolite by unconformity at Semero (Uk-101123-04) of Dila west.

Correlation : This layer distributed at Dila west corresponds to Rhyolites, trachytes, ignimbrites with minor tuff and basalt (PNv) of A laji Formation with Shole Ignimbrite (Halcrow, 2008). On the other hand, this layer is correlated with Qbl (Lower Quarternary "Tena Bilate" Basalts) which is distributed widely from along Riv. Bilate to the north of Lake Abaya (GSE, 2002 Geothermal Resource Exploration in the Abaya and Tulu Moye-Gedemsa Geothermal Prospects, Main Ethiopian Rift). However in this study, this basalt is different from the "Tena Bilate" basalts distributed along the Riv. Bilate, because the above basalt which is distributed widely in the north of Lake Abaya abuts the pumice flow belonging to Duguma Fango Volvanics at the southwest of Mt. Bula (Uk-101117-05).

Southern Kebado (Uk-101125-06) | Western Kebado (Uk-101125-07)

Figure 2.25: Type Locality and Lithology of Kebado Basalt

c. Basaltic Pyroclastics

The strata correlated in each area are unified by this member.

Adami Tulu basaltic pyroclastics

Lithology : Yellowish brown basaltic lapilli tuff to tuff breccia, containing rhyolitic sub-angular fragments is observed at type locality. Lamination are well developed in the unit and vitric matrix may indicate hyaloclastic condition. Distinctive silicic tuff layer is partially intercalated. In Adami Tulu, the unit is around 12^0 dipping to the north.

Distribution : Forms a hill at Sendicho Kebele in southern side of Lake Ziway, remaining hills at the rift floor in Adami Tulu and flat plain (EL.1760m) at the top of Gademotta hill.

Thickness : More than 60m at type locality

Type locality : Adami Tulu, south of Lake Ziway (Uk-100209-01)

Relationship with lower unit : The unit overlies Ogolche Basalt by unconformity at Sendicho Kebele (Uk-100210-03) and Gademotta Rhyolite by unconformity at Gademotta hill (Uk-100630-01).

Correlation : The unit is classified as Qwh: Basalts of the floor in Halcrow (2008), Qω: Alutu-Bericho rhyolitic lava flows, unwelded pumice fall and pantelleritic obsidian flow at Adami Tulu and Qcg: Middle Pleistocene colluvial-alluvial gravel, sand, silt and pyroclastic at Gademotta in Dainelli et al. (2001), and Qj:

Lacustrine sediments, silts, clays, diatomites, volcanoclastic sediments and tuffs in EWTEC (2008).

Uk-100209-01   Adami Tulu

Figure 2.26: Type Locality and Lithology of Adami Tulu Basaltic Pyroclastics

Shala Senbete basaltic pyroclastics

Lithology : Consists mainly of dark gray to black basaltic tuff breccia. A cliff at type locality, basaltic tuff breccia containing rhyolite breccia of approx. 1-2cm overlies Lepis Basalt by unconformity. Laminated volcanic sand and basaltic lapilli tuff are intercalated in this basaltic tuff breccia. Generally the unit has NE-SW strike and gently dipping to the NW. In Lake Chitu (Uk-100602-03), basaltic tuff breccia is exposed at the 10-15m high caldera wall. That tuff breccia consists of scoriaceous matrix with sub-angular basaltic breccia, intercalates volcanic sand laminations. Outcrop surface are whitely-altered, which is caused by hydrothermal alteration.

Distribution : Forming flat plain at southwestern side of Lake Shala. Following the N-S fault at the north of Shala Senbete, caldera wall of Lake Chitu and west of Lake Chitu

Thickness : More than 20m at type locality and southwestern side of Lake Shala. More than 15m at northern caldera wall in Lake Chitu.

Type locality : Shala Senbete, Southwest of Lake Shala (Uk100309-05)

Relationship with lower unit : The unit overlies Lepis Basalt by unconformity at type locality, however the boundary is unclear. The unit overlies Aje rhyolite at southwestern side of Lake Shala (Uk-101224-06).

Correlation : The unit is classified as Qwdp: Basalts of the floor in Halcrow (2008) and Qfl: Wonji-Butajira basaltic lava flow in Dainelli et al. (2001)

Uk-100309-05 Shala Senbete

Figure 2.27: Type Locality and Lithology of Shala Senbeta Basaltic Pyroclastics

Abaye Ridge basaltic pyroclastics

Lithology : Consists of yellowish brown basaltic tuff breccia to lapilli tuff. At type locality, epiclastic tuff breccia containing basalt and rhyolite breccia (dia. 5-20cm) with basaltic scoriaceous matrix is observed more than 20m from the bottom, and change to the alternation of basaltic tuff breccia and volcanic sand at the top. The strike is N15^{0}E-N30^{0}E and the dip is 20^0 W – 30^{0}W. At a hill in Shalo (Uk-100607-01), northward of Lake Awasa, a 60m thick alternation of basaltic tuff breccia and scoriaceous volcanic sand (N30^{0}E32^{0}W) is exposed. The lower part contains vitric matrix, may indicate subaqueous eruption. At western part of a cliff located northward of Lake Cheleleka (Uk-100602-05), basaltic tuff breccia underlies alternation of white tuff, well-compacted lapilli tuff and tuff breccia. At eastern part, alteration of lapilli tuff and scoriaceous volcanic sand overlies Wendo Genet rhyolite. Plagioclase and obsidian contained tuff are intercalated in those alternations.

Distribution : NE-SW distribution at Abaye Ridge west of Lake Awasa, the cliff north of Lake Cheleleka overlying Wendo Genet rhyolite and isolated hills at eastern and northern side of Lake Awasa.

Thickness : More than 120m at Abaye Ridge and the cliff the north of Lake Cheleleka

Type locality : Shalo hill (Uk-100607-01)

Relationship with lower unit : The unit overlies Wendo Genet rhyolite at the cliff the north of Lake Cheleleka (Uk-100602-05).

Correlation : The unit is classified as Qwbp: Basalts of the floor, NQs of Dino Formation, Qwa and Qwpu in Halcrow (2008), and Qwtl of Dino Formation, Qlib: Basalts of the floor, Qwbp and Qvs in GSE (2003).

Chronology : 1.27±0.1My K-Ar Age from the south of Abaye Ridge and 0.96±0.1My K-Ar Age from obsidian-containing tuff at the cliff in the northward of Lake Cheleleka.


Uk-100603-01 Abaye Ridge

Figure 2.28: Type Locality and Lithology of Abaye Ridge Basaltic Pyroclastics

Donga Basaltic pyroclastics

Lithology : Mainly consists of dark brown tuff, volcanic sand, dark brown to black basaltic tuff breccia. The dark brown basaltic tuff breccia is distributed at type locality, but the relationship between kebado Basalt and these strata is unclear. The alternating strata of the dark brown tuff with lamination and brown volcanic sand gently decline to the direction of southern west (Lake side). The surface of tuff is partly altered to a white bubble formation.

Distribution : Type locality and northern west of Mt. Donga at northern area of Lake Abaya (Uk-101126-05).

Thickness : About 60m+ at northern west of Mt. Donga at northern area of Lake Abaya (Uk-101126-05).

Typelocality : Semero-Laluncha (Uk-101123-02) at west of Dila

Relationship with lower unit: These strata overlay Kebado Basalt by unconformity at the type locality, however the boundary is unclear.

Correlation : These strata distributed at type locality correspond to Rhyolites, trachytes, ignimbrites with minor tuff and basalt (PNv) of A laji Formation with Kebado Basalt (Halcrow, 2008). On the other hand, these strata correlate with Qrl (Abaya Rhyolites) (GSE, 2002 Geothermal Resource Exploration in the Abaya and Tulu Moye-Gedemsa Geothermal Prospects, Main Ethiopian Rift).

Northwetern foot of Mt.Donga, north of Lake Abaya (Uk-101126-05)

Figure 2.29: Type Locality and Lithology of Donga Basaltic Pyroclastics

d. Strongly Green Welded Tuff

The strata correlated in each area are unified by this member.

Gonde green strongly welded tuff

Lithology : Consists mainly of blueish gray to green strongly welded rhyolitic fine welded tuff. The unit is massive and partially contains white pumice, basaltic and rhyolitic fragments, and obsidians. Hexagonal fractures (probably columnar joint) are partially developed in Riv. Gonde, which is considered as an aquifer of Gonde Spring.

Distribution : The foot of Deneba Ridge at Chafe in the south of Asela, Riv. Gonde, Riv. Kulmusa, the north of Asela. Lenticular distribution is observed between Asela-Ogolcho restricted by step-down normal faults.

Thickness : More than 20m at type locality and more than 30m at Deneba Ridge

Type locality : Riv. Gonde, the north of Asela (Uk-100317-01)

Relationship with lower unit : The unit may overlie Adami Tulu basaltic pyroclastics, however the boundary was not found. Unconformity boundary is expected based on the No.3 drilling log of the study. The unit overlies Hangasu Rhyolite by unconformity and underlies Butajira Recent basalt by unconformity at Chufa in the south of Ogolcho (Uk-101215-04).

Correlation : The unit is classified as N1_2n: Stratoid Silicics of Nazareth Formation in Halcrow (2008) and T τ : Volcanites of the Plateux in Dainelli et al. (2001).

Uk-100317-01 Riv.Gonde

Figure 2.30: Type Locality and Lithology of Gonde Green Strongly Welded Tuff

Bilate River green strongly welded tuff

Lithology : Consists mainly of blueish gray to green strongly welded rhyolitic-andestic fine welded tuff. The unit is massive and partially contains white pumice, basaltic and rhyolitic fragments, and obsidians. Some of the part is altered and greenish colour is shown. Hexagonal fractures (probably columnar joint) are especially developed. At type locality, the unit underlies pumice flow deposit of Lake Shala acidic volcano sedimentary rocks by unconformity. The unit is burned by the overlying unit at the boundary. At Bilate River in Kulito, the unit underlies white tuff containing ash pisolite of Lake Shala acidic volcano sedimentary rocks by unconformity. Hexagonal fractures (probably columnar joint) are specially developed in this location. Approximate elevation of the unit is EL.1700m at eastern wall and EL.1620m at northern wall in Lake Shala indicates the unit may have been uplifted in a southward direction.

Distribution : 10m-high cliff is continuing in eastern wall of Lake Shala, Bilate River near Kulito Riv.Weyra, Riv.Limaze and eastern foot of Mt. Lencho in Aje. In Munesa, the unit is widely distributed by forming 20m-high hills.

Thickness : More than 10m at type locality, more than 6m in Mt. Lencho and more than 20m in Munesa. 20m+ along Riv. Bilate.

Type locality : Eastern caldera wall in Lake Shala (Uk-100527-02), Riv. Bilate at Kulito (Uk-100212-05）

Relationship with lower unit : The unit may overlie Shala Senbete basaltic pyroclastics, however the boundary was not found. The relationship directly between this stratum and Adami Tulu basaltic pyroclastics below at the outcrop is unclear. Unconformity boundary is expected based on the No.3 drilling log of our study.

Correlation : The unit is classified as Ql at type locality and Qdi and Qdp at Bilate River in Halcrow (2008), and P ρ : Rift floor ignimbrite in Dainelli et al. (2001).

Chronology : 0.21±0.01My K-Ar age from Bilate River near Kulito by WoldeGabriel et al. (1990)

Figure 2.31: Type Locality and Lithology of Bilate River Green Strongly Welded Tuff

Hantate green strongly welded tuff

Lithology : Consists mainly of blueish gray to green strongly welded rhyolitic-andestic welded tuff. The unit is massive, and partially contains white pumice, basaltic and rhyolitic fragments, and obsidians. Hexagonal fracture is generally developed. At the bank of Bilate River in Kulito (Uk-100212-05), Hexagonal fracture is typical in the unit. At Mt.Borena (Uk-100629-02), the unit is silicified and shows greenish color, that overlies Wendo Genet rhyolite. Based on the exposed elevation, the unit may be lifting up to in a southward direction. This layer forms the wall rock of 30m in height at Riv.Gidabo east wall of Riv.Gidabo of west Chuko (Uk-101124-04,05) and is underlaid by Yirga-Alem acidic volcano sedimentary rocks by unconformity. This layer is distributed by lens at low land of river in distributed area of Yirga-Alem acidic volcano sedimentary rocks in west of Sodo to Bohicha and its surrounding area.

Distribution : N-S ridge of Mt. Kuwe – Bolicha Ridge south of Awasa, river bank of Bilate River in Dimtu and east of Mt. Borena, westward of Corbetti Volcano and Korbeti in the south of Mt. Urgi. West of Yirga Alem to along the ridge towards the south. From Dila to Chuko. Sodo to Hobicha and its surrounding area along the river.

Thickness : More than 15m at type locality, more than 6m Mt.Kuwe and Mt. Borena. About 30m at east wall of Riv. Gidabo (Uk-101124-04,05)

Type locality : Hantate, westward of Yirga Alem (Ho-100429-02)

Relationship with lower unit : The unit overlies the upper part of Wendo Genet rhyolite by unconformity at Mt. Borena. The unit may overlie Abaye Ridge Basaltic Pyroclastics, however the boundary was not found.

Correlation : The unit is classified as Qdp of Dino Formation and Qwh, Qwdp of Basalts of the floor in Halcrow (2008), and Qdi: Dino Formation and Qvs in EGS. (2003). (GSE, 2002, Geothermal Resource Exploration in the Abaya and Tulu Moye-Gedemsa Geothermal Prospects Main Ethiopian Rift)

Chronology : 0.21±0.01My K-Ar age from Bilate River near Kulito by WoldeGabriel et al. (1990)

Ho-100429-02 Hantate

Dila quarry site(Uk-1122-01)

West Dila Semero (Uk-101123-04)

Figure 2.32: Type Locality and Lithology of Hantate Green Strongly Welded Tuff

e. Acidic Volcano-Sedimentary Rocks

The strata correlated in each area are unified by this member.

Ketar River acidic volcano sedimentary rocks

Lithology : Consists of white pumice tuffs, tuffs and their alternations deposited by pumice flows. Alternation of pumiceous sand and silt observed in Ketar River (Uk-100518-07) may indicate epiclastic lake deposits. The top of this unit became palaeosol and unconformably overlain by Kulmusa Highly Welded Tuff.

Distribution : Riv. Ketar near Ogolche, northeast of Lake Ziway, Hangasu, southeast of Lake Ziway and Deneba Ridge, northwest of Asela

Thickness : More than 20m at type locality (Uk-100518-07) and more than 50m in Deneba Ridge, east of Deneba (Uk-101214-03).

Type locality : Riv. Ketar near Ogolche, northeast of Lake Ziway (Uk-100317-01)

Relationship with lower unit : The unit overlies Gonde strongly Welded Tuff by unconformity at Deneba Ridge in the east of Deneba. The unit forms a flat plain and overlies Ogolche Basalt by unconformity at Hangasu in southeast of Lake Ziway (Uk-101214-03). The unit also overlies Gademotta Rhyolite by unconformity at Mt. Goda in the south of Gademotta Caldera.

Correlation : The area is classified as Qdi: Dino Formation at Kulmusa and Ql at Ketar River in Halcrow (2008), and T τ : Volcanites of the Plateux and P ρ : Rift Floor Ignimbrite at Kartar River in Dainelli et al. (2001).

Figure 2.33: Type Locality and Lithology of Ketar River Acidic Volcano Sedimentary Rocks

Lake Shala acidic volcano sedimentary rocks

Lithology : Consists of white pumice tuffs, tuffs and their alternations deposited by pumice flows and lake-land environment. At type locality, pumice flow deposit containing rholite and welded tuff fragments, thin alternation of pumice and blueish gray laminated volcanic sand, and gray tuffs containing white pumice observed in a thickness of 60 to 150m.

Distribution : The unit is exposed at the upper part of eastern wall in Lake Shala. The unit also forms a flat plain which is located in the west of Lake Abijata, Lake Shala and around Aje. The unit is also distributed as gentle slope from eastern Kuyera to Kofele in the east of Lake Shala.

Thickness : 60-150m at type locality

Type locality : Eastern caldera wall in Lake Shala (Uk-100527-06)

Relationship with lower unit : The unit overlies Bilate River strongly Welded Tuff at the type locality and at the bank of Bilate River near Kulito (Uk-100212-05).

Correlation : The area is classified as Qdi: Dino Formation and Qdp in Halcrow (2008), and P ρ : Rift Floor Ignimbrite at Kartar River in Dainelli et al. (2001).

Uk-100527-06 Lake Shala

Figure 2.34: Type Locality and Lithology of Lake Shala Acidic Volcano Sedimentary Rocks

Amecho acidic volcano sedimentary rocks

Lithology : Consists of pumiceous tuff with white pumice flow mainly, white tuff and its alternation. And also lake deposits with fine sand containing many white pumice developed lamination and silt and its alternation along Riv. Limaze (Uk-101207-04). The alternation of fine sand and silt deposits are overlaid by pumice flow consisted by white to yellowish white pumice by unconformity at type locality (Uk-100318-03). These strata, in particular, a part of redish bark paleo-soil is eroded by water, and are characterized by eroded topography over a wide area.

Distribution : From Hosaina to Werabey with wide flat plain

Thickness : 20m; at type locality

Typelocality : west Amecho (Uk-100318-03）

Relationship with lower unit : pumice flow deposits overlay Bilate River Strongly Welded-Tuff by unconformity along Riv. Bilate, Riv.Limaze, etc. These strata also overlay Gademotta Rhyolite by unconformity at Gademotta caldera.

Correlation : These strata correspond to Qdi and N1_2n（Stratoid Silicics）from Hosaina to Amecho (Halcrow, 2008). These strata are also correlated with P ρ（Rift Floor Ignimbrite）and Qc（Colluvial-alluvial gravel, sand, silt and pyroclastic）, cg（Colluvial-alluvial gravel, sand, silt and pyroclastic）distributed at upper part of Gademotta caldera (Dainelli et al., 2001). These strata correspond to Qdi and Qa (EWTEC, 2008).

West of Amecho (Uk-100318-03)

Figure 2.35: Type Locality and Lithology of Amecho Acidic Volcano Sedimentary Rocks

Yirga Alem acidic volcano sedimentary rocks

Lithology : Consists mainly of white pumice tuffs, tuffs and their alternations deposited by pumice flows and lake-land environment. The lower part of unit contains ash-pisolite. At type locality, pumice flow deposit containing rhyolite and welded tuff fragments is observed in a thickness of 10 to 15m at a cliff. At Mt. Kuwe (Uk-100524-01), the unit consists of at least three flow layers and overlies the paleosol of Hantate green strongly welded tuff by unconformity. At Hantate, the unit is whitish tuff containing ash-pisolite overlies Hantate green strongly welded tuff by unconformity. From Abaye Ridge to Bilate River and Yirba to Kulito, land deposit of the upper part covers the surface. After deposition, the unit is weathered deeply and turns into soil.

Distribution : West to Southwest of Abaye Ridge, South of Awasa to Yirga Alem and Bilate River, Mt. Kuye in the south of Awassa and eastern Shashamane to Kofele. The unit covers widely in the rift floor of this area.

Thickness : More than 15m at type locality, 90m at Mt. Kuwe, more than 100m at western wall of Awasa. about 100m at east wall of Riv. Gidabo (Uk-101124-05)

Type locality : South of Yirga Alem (Uk-100213-08)

Relationship with lower unit : The unit overlies Hantate strongly Welded Tuff at Mt. Kuwe (Uk-100524-01).

Correlation : The area is classified as Qdi: Dino Formation, Qdp, Ql and Qvs in Halcrow (2008), and Qdi: Dino Formation, Qdp, Qwt1, Qwt2 and Qvs in GSE (2003), (GSE, 2002, Geothermal Resource Exploration in The Abaya and Tulu Moye-Gedemsa Geothermal Prospects, Main Ethiopian Rift)

Uk-100213-08 Yirga Alem

Ho-100429-02 Pisolite, Hantate

Figure 2.36: Type Locality and Lithology of Yirga Alem Acidic Volcano Sedimentary Rocks

f. Highly Welded Tuff

The strata correlated in each area are unified by this member.

Kulmusa highly welded tuff

Lithology : Consists of dark blueish gray to dark gray rhyolitic to andestic welded tuff which typically contains obsidian lens (fiamme). Ion type locality, the unit overlies Ketar River volcano sedimentary rocks by unconformity. The unit is strongly welded with maximum 50cm-long fiamme, accompanied by 50cm-thick unwelded part at the bottom. The unit contains rhyolite, green welded tuff, white pumice and rarely basaltic fragments and reverse grading of lithic fragments are observed. Normal grading of fiamme indicates that the welding is weak in the upper part. The uppermost part of the unit consists of dark gray vitric tuff without lithic fragments. The unit observed at Koshe in east of Butajira and Mt. Chebi in the south of Gademotta Caldera, contains many fragments, and fiamme is not elongated.

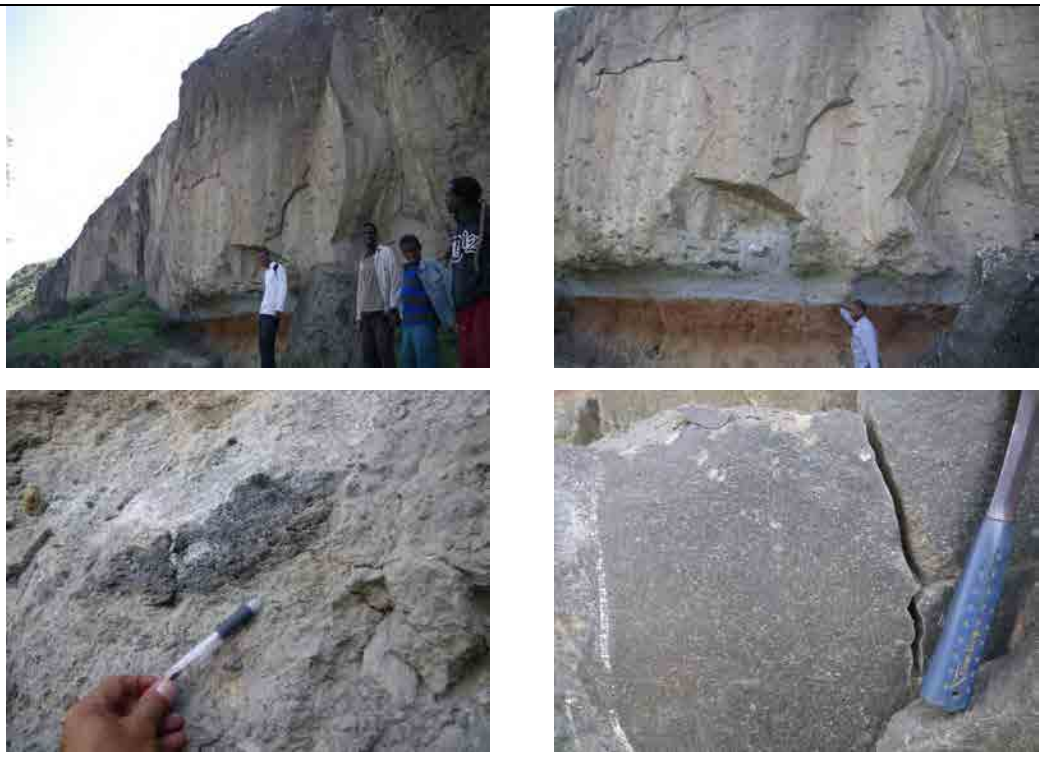
Distribution : Deneba Ridge (west of Kulmusa), Ketar River Fall (southwest of Asela Town) and Koshe (East of Butajira)

Thickness : About 10m at type locality.

Type locality : Deneba Ridge, west of Kulmusa (Uk-100317-04)

Relationship with lower unit : The unit overlies Ketar River acidic volcano sedimentary rocks by unconformity at the type locality and Gademotta Rhyolite by unconformity at Mt. Chebi in the south of Gademotta Caldera.

Correlation : The area is classified as Qdi: Dino Formation in Halcrow (2008), T τ : Volcanites of the Plateux in Dainelli et al. (2001) and Qdi: Dino Formation in EWTEC (2008)



Uk-100317-04 Kulmusa

Figure 2.37: Type Locality and Lithology of Kulmusa Highly Welded Tuff

Kuyera highly welded tuff

Lithology : Consists of dark blueish gray to dark gray rhyolitic to andestic welded tuff which typically contains obsidian lens (fiamme). The unit contains rhyolite, green welded tuff, white pumice and rarely basaltic fragments. The unit is well compacted and strongly-resistant against erosion, generally forms steep cliffs. At type locality, the size of fiamme is maximum 30cm, average 7-10cm in length, and approx. 2cm in thickness. In the west of the type locality, average length is 3-5cm and 1cm in thickness. In outer wall of Lake Shala (Uk-100610-12), average length is 5cm and 1cm in thickness. In Mt. Kulisa (Uk-100622-05), average length is 2-3cm and 0.5-1cm in thickness. In roadside of the north of Arsi negele, average length is 5-10cm and 1-2cm in thickness. In the west of Lake Langano and east of Lake Abijata, average length is 10cm and 2-4cm in thickness. The above data shows that the fiamme is larger where the unit is closer to Lake Shala and Lake Abijata.

Approximate elevation of the unit is EL.1750m at eastern wall and EL.1690m at northern wall in Lake Shala, 1580m to 1600m in Lake Abijata and Lake Langano indicates the unit seems to be lifting up in a southward direction.

Distribution : Eastern side in Lake Abijata, western side in Lake Langano, eastern wall in Lake Shala, bottom of streams from Arsi Negele to Sheshemene and part of Mt. Kulisa.

Thickness : More than 15m at type locality and more than 20m at Lake Shala.

Type locality : Quarry site in Kuyera, south of Arsi Negele (Uk-100610-04)

Relationship with lower unit : The unit overlies Lake Shala acidic volcano sedimentary rocks by unconformity at the eastern wall of Lake Shala.

Correlation : The area is classified as Ql at the type locality, Qdi: Dino Formation and Qdp in the west of Lake Shala to the west of Lake Abijata in Halcrow (2008) and P ρ : Rift Floor Ignimbrite at Kartar River in Dainelli et al. (2001).

Uk-100610-04 Kuyera

Figure 2.38: Type Locality and Lithology of Kuyera Highly Welded Tuff

Koshe highly welded tuff

Lithology : Dark bluish brown to brown fine to medium rhyolite to andesitic welded tuff characterized by flat obsidian. The flat degree of obsidian in welded tuff is few and welded tuff contains many accidental fragments at type locality. The Amecho acidic volcano sedimentary rocks distribute to the west of fault located along the river, on the other hand, the Gademotta Rhyolite distribute to the east of fault at Gedilala (UK-101210-02) located in the north east direction of Koshe. This stratum forms the wall rock and overlays the Amecho acidic volcano sedimentary rocks by unconformity. The Amecho acidic volcano sedimentary rocks are distributed below this stratum at Dugda (Uk-101210-03) downstream of Riv. Meki. The welded tuff contains the flat obsidian of the maximum 20cm in length, rhyolite, green strongly welded tuff, white pumice fragment and basaltic fragment rarely. This stratum, Koshe type including accidental fragment, overlays Amecho acidic volcano sedimentary rocks at Kudusa and Mt. Chebi (1975m in height : Uk-101112-04) of southern area of Gademotta caldera.

Distribution : Hilly area from Koshe to along the Riv.Meki. By the mountaintop of Mt.Chebi、Mt.Gofa of the south area of Gademotta caldera

Thickness : about 20m; at type locality

Type locality : Koshe（Uk-100210-01）

Relationship with lower unit : This stratum overlay Gademotta Rhyolite、Amecho acidic volcano sedimentary rocks by unconformity at by Gedilala (UK-101210-02) northeast of Koshe.

Correlation : This stratum is correlated with Qdi of Dino Formation (Halcrow, 2008), and Qu（Undifferentiated colluvial-alluvial gravel, sand, silt and pyroclastic）(Dainelli et al., 2001). This stratum distributed to upper part of Gademotta caldera corresponds to Qc（Colluvial-alluvial gravel, sand, silt and pyroclastic）(Dainelli et al., 2001), and Qdi (EWTEC, 2008).

Koshe (Uk-100210-01)

Figure 2.39: Type Locality and Lithology of Koshe Highly Welded Tuff

Mt.Kuwe highly welded tuff

Lithology : Consists of dark blueish gray to dark gray rhyolitic to andestic welded tuff which typically contains obsidian lens (fiamme). The unit contains fiamme, rhyolite, green welded tuff, white pumice and rarely basaltic fragments. The unit is well compacted and strongly-resistant against erosion, generally forms a steep cliff. At Mt. Kuwe (Uk-100524-02), the size of fiamme is on average 5cm in length. At Danshe (Uk-100619-06), west of Yirga Alem, the size of fiamme is on average 1-2cm in length. Generally, the fiamme is horizontal and concordant with the unit, however steeply tilted around 56^0 to the north at Mt. Kuwe.

Distribution : Mt. Kuwe, southern side of Lake Awasa, along the ridge from Boricha Ridge to the south.

Thickness : 20m at type locality and 10-15m at the ridge in the south.

Type locality : Mt. Kuwe, southern side of Lake Awasa (Uk-100524-02)

Relationship with lower unit : The unit overlies Yirga Alem acidic volcano sedimentary rocks by unconformity at Mt. Kuwe.

Correlation : The area is classified as Ql, Qdi: Dino Formation and Qws in Halcrow (2008) and Qdi: Dino Formation, Qws: Basalts of the floor and Qvs: Central volcanic Complex in GSE (2003).


Uk-100524-02　Mt.Kuwe

Figure 2.40: Type Locality and Lithology of Mt. Kuwe Highly Welded Tuff

Samero highly welded tuff

Llthology : Consists of dark bluish brown to dark brown rhyolite to andesitic fine to medium welded tuff characterized by flaked obsidian. This stratum contains flaked obsidian, rhyolite, green strongly welded-tuff, white pumice chip, and basalt chip rarely. This stratum forms massive wall rock.

Distribution : Samero of west Dila, and west wall of Rive.Gidabo at west of Chuko.

Thickness : 5m+ at type locality, 20m+ at west wall of Rive.Gidabo

Type locality : Samero (Uk-101122-02） west of Dila

Relationship with lower unit : This stratum overlays Yirga-Alem acidic volcano sedimentary rocks by unconformity at type locality and Riv. Gidabo (Uk-101124-05) west of Chuko.

Correlation : This stratum corresponds to Ql at type locality and Qdi and Qdp of Dino Formation from west of Lake Abiyata to west of Lake Shala (Halcrow, 2008).


Samero, west of Dila (Uk-101122-02)

Figure 2.41: Type Locality and Lithology of Samero Highly Welded Tuff

g. Poorly Welded Pumiceous Pyroclastics

The strata correlated in each area are unified by this member.

Asela poorly welded pumiceous pyroclastics

Lithology : Consists of yellow to yellowish white rhyolitic pumice tuff. The unit is accompanied with 2m-thick welded part at the bottom. The unit contains rhyolite, green welded tuff and white pumice fragments. The lower part contains much lapilli and upper part contains many pumices, indicates normal grading in the unit.

Distribution : Deneba Ridge (west of Kulmusa)

Thickness : About 10m at type locality.

Type locality : Deneba Ridge, west of Kulmusa (Uk-100317-04)

Relationship with lower unit : The unit overlies Kulmusa highly Welded Tuff by unconformity at the type locality.

Correlation : The area is classified as Qdi: Dino Formation in Halcrow (2008), T τ : Volcanites of the Plateux in Dainelli et al. (2001).


Uk-100317-04 Kulmusa

Figure 2.42: Type Locality and Lithology of Asela Poorly Welded Pumiceous Pyroclastics

Langano poorly welded pumiceous pyroclastics

Lithology : Consists of yellow to yellowish white rhyolitic pumice tuff deposited by pumice flow. At type locality, the unit consists of well-bubbled white pumice which has an average diameter of 10-30cm and contains rhyolite, basalt and obsidian fragments of lower parts, and normal grading of pumice is partly observed. In the south of type locality, obsidian layer in upper part of Kuyera highly welded tuff was crushed and the unit is overlain by an unconformity. The unit is observed 15-30m in thickness at western side of Lake Langano and eastern wall of Lake Abijata. The unit is widely distributed in the plain between Lake Langano and Shashemene. The unit is observed with overlying Kuyera highly welded tuff at the banks of the stream in this area.

Distribution : Western side of Lake Langano, eastern wall of Lake Abijata and the plain area between Lake Langano and Shashemene.

Thickness : More than 30m at type locality.

Type locality : Western side of Lake Langano (Uk-100305-01)

Relationship with lower unit : The unit overlies Kuyera highly welded tuff by unconformity at the south of the type locality.

Correlation : The area is classified as Ql at the type locality and Qdi: Dino Formation at around Lake Shala in Halcrow (2008), and Pρ: Rift floor ignimbrite in Dainelli et al. (2001).

Uk-100305-01 Lake Langano

Figure 2.43: Type Locality and Lithology of Langano Poorly Welded Pumiceous Pyroclastics

Dugba poorly welded pumiceous pyroclastics

Lithology : Porous yellow to yellowish white rhyolitic pumiceous tuff containing white pumice and gravel of green welded tuff. The lower part of this stratum contains a lot of lapilli, and the normal grading structure containing lots of pumice is indicated in the upper part of this stratum.

Distrubution : From Gedilala located in midstream of Riv.Meki to the upper part of hilly area of Dugba and its surrounding area.

Thickness : about 5m+ at type locality

Type locality : Gedilala located in midstream of Riv.Meki（Uk-101210-03）

Relationship with lower unit : These strata ovelay Koshe highly welded-tuff by unconformity at type locality.

Correlation : These strata correspond to Qdi of Dino Formation (Halcrow, 2008), and P ρ (Rift Floor Ignimbrite)（Dainelli et al., 2001).

Gedilala (Uk-101210-03)

Figure 2.44: Type Locality and Lithology of Dugba Poorly Welded Pumiceous Pyroclastics

Shashemene poorly welded pumiceous pyroclastics

Lithology : Consists mainly of yellow to yellowish white rhyolitic pumice tuff. The unit forms the plain surrounding Shashemene. The unit is observed only in Mt. Kuwe, type locality, forming the plain at the top. At type locality, compacted tuff is observed to contain yellow to yellowish white pumice.

Distribution : Widely distributed in the plain surrounding Shashemene, small distribution at Mt. Kuwe, southern side of Lake Awasa.

Thickness : 25m at type locality

Type locality : Mt. Kuwe, southern side of Lake Awasa (Uk-100524-02)

Relationship with lower unit : The unit overlies Mt.Kuwe highly welded tuff, however the boundary was not found. According to the distribution unconformity boundary is considered.

Correlation : The area is classified as Ql and Qdi: Dino Formation in Halcrow (2008), and Qdi: Dino Formation, Qws: Basalts of the floor in GSE (2003).

Uk-100524-03 Mt.Kuwe

Figure 2.45: Type Locality and Lithology of Shashemene Poorly Welded Pumiceous Pyroclastics

2.3.8 Quaternary Holocene

a. Lacustrine1

The strata correlated in Lake Ziway and Lake Awasa area are unified by this member.

Meki lacustrine deposits

Lithology : Consists of thin alternation of pumice and laminated volcanic sand. The unit forms flat plain around EL.1680m from west of Meki to west of Abosa.

Distribution : Toward Meki River and the plain from west of Meki to west of Abosa.

Thickness : 10-20m at type locality

Type locality : Bole, southwastern part of Meki (Uk-101112-01)

Relationship with lower unit : The unit overlies Asela poorly welded pumiceous pyroclastics by unconformity at the type locality.

Correlation : The area is classified as Ql in Halcrow (2008), Qll in Dainelli et al. (2001) and Qj: Lacustrine sediments, silts, clays, diatomites, volcanoclastic sediments and tuffs in EWTEC (2008).

Bole（Uk-101112-01）

Figure 2.46: Type Locality and Lithology of Meki Lacustrine Deposits

Wondotika lacustrine deposits

Lithology : At the type locality, the following layers are observed from the bottom; thin alternation of pumice and laminated volcanic sand, poorly-sorted sub-angular to sub-round gravel including 20cm-diameter rhyolite and white to blueish gray pumice, white tuff and alternation of pumice and sand. The unit overlies paleosol of Yirga Alem acidic volcano sedimentary rocks, and overlain by scoria layer of Awasa Recent Basalt, pumice fall of Corbetti Volcanics and black soil at the top. At Jara Damwa, southern side of Lake Awasa (Uk-100226-04), the unit overlying Wendo Genet Rhyolite forms gentle slope at the height of 60m from alluvial plain. The unit forming a gentle plain consists of blueish gray to gray fine - medium laminated pumiceous sand.

Distribution : Gentle slopes below EL. 1780m which is located in Rima, northwestern side of Lake Awasa – west of Abaye and Jara Damwa, south saide of Lake Awasa.

Thickness : More than 30m at type locality

Type locality : Rima, northwestern side of Lake Awasa (Uk-100531-02)

Relationship with lower unit : The unit overlies Yirga Alem acidic volcano sedimentary by unconformity at the type locality. The unit might overlie Shashemene poorly welded pumiceous pyroclastics, however the boundary was not found. According to the distribution, unconformity boundary is considered.

Correlation : The area is classified as Ql in Halcrow (2008) and Qla, Qvs in GSE (2003).

Uk-100531-02 Wondokita, Northwestern side of Lake Awasa

Figure 2.47: Type Locality and Lithology of Wondotika Lacustrine Deposits

b. Recent Basalt

The strata correlated in each area are unified by this member.

Deneba recent basalt

Lithology : Consists of dark gray to dark blueish gray olivine-bearing basalt lava and dark brown to reddish brown scoria falls. At the type locality, dense basaltic lava is found at the bottom, and changed to porous or scoriaceous in upward. Hexagonal-shaped columnar joint is often formed in dense basalt lava at Gojero in the north of Deneba (Uk-101214-03).

Distribution : Linear distribution of NE-SW near Deneba in northeast of Ogolcho, along the fault zone.

Thickness : 30m at type locality

Type locality : Southwestern part of Deneba (Uk-101214-14).

Relationship with lower unit : The unit overlies Gonde Green Strongly Welded Tuff by unconformity at type locality, Amecho acidic volcano sedimentary rocks by unconformity at Gojero in the north of Deneba (Uk-101214-03).

Correlation : The unit is classified as Qwa: Basalts of the rift floor in Halcrow (2008), Qfl: Wonji-Butajira basaltic lava flows and scoria cones in Dainelli et al. (2001) and Qwbh: Basalts of the rift floor in EWTEC (2008).

Northwestern Deneba (Uk-101214-14)

Gojero (Uk-101214-03)

Figure 2.48: Type Locality and Lithology of Deneba Recent Basalt

Awara recent basalt

Lithology : Consists of dark gray to dark blueish gray olivine-bearing basalt lava and dark brown to reddish brown scoria falls. Generally basaltic scoria is underlain by hard basalt lava. At type locality, hard basalt lava with platy joint underlies scoriaceous basaltic lava and reddish gray scoria deposits. Fumarole is observed at type locality. In Bura (Uk-100330-01), basaltic scoriaceous volcanic cone is overlain by whitish pumice fall, which is considered to be supplied from Mt. Chebi or Mt. Urzi).

Distribution: Southwestern side of Lake Shala – southwestern part of Shala Senbete – Awara. Scoriaceous volvanic cones are formed in Awara and Bura, and scoriaceous volvanic cones are lined toward NNE-SSW faults (Uk-100628-03~05)

Thickness : 20m at type locality

Type locality : Shala Senbete, Southwestern side of Lake Shala (Uk-100309-04)

Relationship with lower unit : The unit may overlie Langano poorly welded tuff, however the boundary was not found. Based on the distribution, the unit is considered to overlie lower units by unconformity.

Correlation : The unit is classified as Qwbp: Basalts of the rift floor in Halcrow (2008) and Qfl: Wonji-Butajira basaltic lava flows and scoria cones in Dainelli et al. (2001).

Uk-100309-04 Shala Senbete

Figure 2.49: Type Locality and Lithology of Awara Recent Basalt

Butajira recent basalt

Lithology : Consists of dark gray to dark blueish gray olivine-bearing basalt lava and dark brown to reddish brown scoria falls. Scoria cones of this unit are mainly observed in Butajira Area. Basaltic scoria is underlain by hard basalt lava at type locality.

Distribution : Linear distribution of NNE-SSW near Butajira Town.

Thickness : 30m at type locality

Type locality : Kibet, south of Butajira Town (UK-100520-01)

Relationship with lower unit : The unit overlies lower units by unconformity.

Correlation : The unit is classified as Qwa: Central Volcanic Complex and Qwbh, Qwh, Qwbp: Basalts of the rift floor in Halcrow (2008), Qfl: Wonji-Butajira basaltic lava flows and scoria cones in Dainelli et al. (2001) and Qwbh: Basalts of the rift floor in EWTEC (2008).

Uk-100520-01 Kibet, South of Butajira

Figure 2.50: Type Locality and Lithology of Butajira Recent Basalt

Awasa recent basalt

Lithology : Consists of dark gray to dark blueish gray olivine-bearing basalt lava and dark brown to reddish brown scoria falls. Generally basaltic scoria is underlain by hard basalt lava. The unit forms 10-20m high gentle mounds in Awasa Town.

Distribution: Scoria cones are distributed at roadside of Shashemene – Aje and Awasa towns. Scoria fall deposit is overlying lower units in the area.

Thickness : 15m at type locality

Type locality : Quarry, north of Awasa University (Uk-100211-09)

Relationship with lower unit : Scoria fall deposit of the unit overlies Wondotika lacustrine deposits by unconformity at Wondotica, northwest of Awasa.

Correlation : The unit is classified as Qwbh, Qwh, Qwbp in Halcrow (2008) and Qwbp: Basalts of the floor in GSE (2003).

Uk-100211-09 Quarry, the north of Awasa University

Figure 2.51: Type Locality and Lithology of Awasa Recent Basalt

Abaya recent basalt

Lithology : Consists of dark bark to redish bark porous scoria fall deposits, and basalt lava containing dark brown to dark bule olivine. The above Lava is classified scoria, and the Lava below becomes fine basalt. The scoria basalt and redish bark scoria are distributed in type locality overlaying the fine basalt with platy joint developed below. The wall rocks distribute continuously to about 8km in direction of N40E at type locality. The wall rock consists of fine & massive basalt (10m thick), massive basalt (8m thick), scoria basalt (3-6m thick), and massive basalt (8-10m thick) from lower part, and the four flow units are recognized. The basalt lava (6-8m thick) is aggraded in depression consisting of Yirga-Alem acidic volcano sedimentary rocks at Bedessa Riv.（Uk-101115-10）of east of Bedessa.

Distribution : From southern part of Dugna Fango to north Lake side of Lake Abaya. The basalt has flowed in the direction of northeast to southwest. The scoria cones are dotted above the lava.

Thickness : about 35m+ at type locality

Type locality : Hobicho Geufu (Uk-101116-06) at east of Mt.Korke

Relationship with lower unit : These strata are overlaid by pumice flow and pumice fall deposits by unconformity at southern west of Mt.Bula (Uk-101117-05).

Correlation : These strata correspond to Qwbp of the rift floor (Halcrow, 2008). On the other hand, these strata correlate with Qb1 (Lower Quarternary “Tena Bilate” Basalts) and Qb2 (Recent Basalts) (GSE, 2002, Geothermal Resource Exploration in The Abaya and Tulu Moye-Gedemsa Geothermal Prospects, Main Ethiopian Rift).

Hobicho Geufu, East of Mt.Korke (Uk-101116-06)

Hill in Bongota (Uk-101116-05)

Figure 2.52: Type Locality and Lithology of Abaya Recent Basalt

c. Holocene Volcanics

The volcanic deposits of each volcanic construction with caldera distributed in each area are unified by this member.

Mt. Aluto volcanics

Lithology : Consists of pumice fall deposits, pumice flow deposits, gray rhyolite lavas and obsidians. These rocks are considered to be formed by alternate eruptions. Two sub-units are recognized in this study; pumiceous sub-unit composed of pumice fall and flows and lava sub-unit composed of rholitic lavas and obsidian lavas. The pumiceous sub-unit consists mainly of pumice fall and flow deposits, which contain little fragments of rhyolite, basalt and welded tuff. At type locality, alternation of white pumice flow and white volcanic sand overlies rhyolite lava which contains obsidians.

Distribution : Mt. Aluto and its surrounding area. The detailed distribution was refered from GSE (1986).

Thickness : Borehole data shows 200-250 thick in the central of Mt. Aluto (GSE, 1986). No distribution was observed outside of Mt. Aluto.

Type locality : Outcrop located beside the pass of the way from Adami Tulu to Sedicho Kebele (Uk-100209-03)

Relationship with lower unit : The unit overlies Bofa basalt by unconformity (GSE, 1986).

Correlation : The area is classified as Qwo, Qwpu in Halcrow (2008), Qω in Dainelli et al. (2001) and Qnpu in EWTEC (2008).


Uk-100209-03 The pass located on the way from Adami Tulu to Sedicho Kebele

Figure 2.53: Type Locality and Lithology of Mt. Aluto Volcanics

Alge volcanics

Lithology : Consists of pumice fall deposits, pumice flow deposits, gray rhyolite lavas and obsidians. The unit includes volcanic deposits of Tulu Fike, Tulu Billa, Lencha Tiko in Alge, Mt.Chebi and Mt. Urzi in Corbetti. The geology in Alge area was refered to by Dainelli et al. (2001).

Distribution : Tulu Fike, Tulu Billa, Lencha Tiko in Alge and its surrounding areas.

Thickness : 300m in Tulu Fike

Type locality : Bura (Uk-100330-01)

Relationship with lower unit : Pumice falls of the unit overlies basaltic scoriaceous volcanic cone of Awara Recent Basalt by unconformity.

Correlation : The area is classified as Qwo, Qwpu in Halcrow (2008).


Uk-100330-01

Figure 2.54: Type Locality and Lithology of Alge Volcanics

Corbetti volcanics

Lithology : Consists of pumice fall deposits, pumice flow deposits, gray rhyolite lavas and obsidians. It is considered that pumice fall and flow deposits are derived from Mt. Urgi, rhyolite lava and obsidian are derived from Mt. Chebi (reference). Those rocks are considered to be formed by alternating eruption. Two sub-units are classified in this study; pumiceous sub-unit composed of pumice fall and flows and lava sub-unit composed of rhyolitic lavas and obsidian lavas. The pumiceous sub-unit consists mainly of pumice fall and flow deposits, which contain little fragments of rhyolite, basalt and welded tuff. Pumice flow deposit is distributed at southeastern and northern side of Mt. Chebi, Mt. Urgi and Mt. Borena. The lava sub-unit consists of rhyolite and obsidian lava with well-developed flow structure and is distributed at the hill and Alge Cape at the northern side of Lake Awasa, the top of Mt. Chebi, the foot of Mt. Urgi. At type locality and Alge Cape, pumice flow deposit underlies obsidian rhyolite lava.

Distribution : Mt. Chebi, Mt. Urgi and surrounding area, northern side of Lake Awasa, northeastern part of Abaye Ridge. Pumice fall deposit is overlying lower units in the area.

Thickness : Approx. 400m in Mt. Urgi, 600m in Mt. Chebi

Type locality : Eastern foot of Mt. Chebi (Uk-100212-02)

Relationship with lower unit : Pumice fall of the unit overlies scoria cone of Awasa Recent Basalt by unconformity at the roadside of Shashemene – Aje (Uk-100330-01).

Correlation : The area is classified as Qwo, Qwpu in Halcrow (2008) and Qwr, Qwa, Qwo, Qwpu, Qlib in GSE (2003).

Chronology : 0.02±0.01My K-Ar age from type locality by WoldeGabriel et al. (1990)


Uk-100212-02 Eastern foot of Mt.Chebi

Figure 2.55: Type Locality and Lithology of Corbetti Volcanics

Duguma Fango volcanics

Lithology : Consists of pumice fall, pumice flow, brown rhyolitic lava and obsidian originated by Dugna Fango, Mt. Korke Mt. Seluwa, and Mt. Bula. The rhyolite lava with obsidian, pumice flow (upper part is fine), pumicious tuff and rhyolitic weakly welded tuff distributed in the east of Dugna Fango (Uk-100325-01). The weathering zone of about ten times is recognized in upper part of pumice flow at west base of the mountaintop (Uk-100325-04). The Recent Basalt overlays pumice flow deposit and pumice fall by unconformity at the hilly area of southern west base of Mt. Bula (Uk-101117-05). Mt. Korke is composed of pumice flow deposits, Mt. Bula located to the north of Mt Korke consists of rhyolite with obsidian, and Mt. Seluwa located in the east of Mt. Korke is composed of obsidian. The geology in Dugna Fango area is classified by GSE, 2002 (Geothermal

Resource Exploration in the Abaya and Tulu Moye-Gedemsa Geothermal Prospects, Main Ethiopian Rift).

Distribution : Dugna Fango, Mt. Korke, Mt.Seluwa, Mt. Bula, and Mt.Donga

Thickness : about 300m at Tulu Fike

Type locality : Dugna Fango（Uk-100325-01＆05),Mt. Korke, Mt.Seluwa and Mt. Bula（Uk-101117-05）

Relationship with lower unit : These strata overlay Yirga-Alem acidic volcano sedimentary rocks by unconformity at Dugna Fango（Uk-100325-01）.

Correlation : These strata correlate with Qwo and Qwpu of Central Volcanic Complex (Halcrow 2008). On the other hand, these strata are composed of Qp1 (Abaya Rhyolites), Qps (Middle-Upper Quaternary Pumiceous Pyroclastics), Qr2 (Duguma Fango Ehyolites), and Qr3 (Recent Rhyo-Obsidian Flow). (GSE, 2002, Geothermal Resource Exploration in the Abaya and Tulu Moye-Gedemsa Geothermal Prospects, Main Ethiopian Rift).

Western foot of Dugna Fango
(Uk-100325-04)

Southwestern foot of Mt. Bula
(Uk-101117-05)

Figure 2.56: Type Locality and Lithology of Dugna Fango Volcanics

d. Lacastrine 2

This member is distributed around each Lake. The strata correlated in each area are unified by this member.

Bulbula lacustrine deposits

Lithology : Consists of thin alternation of pumiceous sand, silt and mud. At type locality, thin alternation of blueish gray to greenish gray volcanic sand and gray tuffeous silt is observed. In southern side of Lake Langano, light brown silt, grey clay, diatomite and pumiceous silt are bedding. Generally bedding plains are horizontal.

Distribution : Horizontal surface of approx. EL.1600m located around Lake Abijata and Lake Langano.

Thickness : More than 20m at type locality

Type locality : National roadside in Bulbura Town (Uk-100310-02)

Relationship with lower unit : The unit overlies overall above-described units by unconformity.

Correlation : The area is classified as Ql: in Halcrow (2008) and Qs2: Shore sand and reworked pumice of poorly preserved strandlines and Qb: Shore sand and reworked pumice in Dainelli et al. (2001).


Uk-100310-02 Bulbula

Figure 2.57: Type Locality and Lithology of Bulbula Lacustrine Deposits

Shalo lacustrine deposits

Lithology : The unit forms a terrace of EL.1710m surrounding Lake Awasa, Lake Cheleleka and Usura, northwest of Lake Awasa, with height of 10m from the alluvial plain.

Distribution : The unit forms terrace of EL.1710m surrounding Lake Awasa, Lake Cheleleka and Usura, northwest of Lake Awasa, with height of 10m from the alluvial plain.

Thickness : 8 - 12m at type locality

Type locality : Southern side of Lake Awasa (Uk-100226-04)

Relationship with lower unit : The unit overlies overall above-described units by unconformity.

Correlation : The area is classified as Ql: in Halcrow (2008), and Qls and Qla in GSE (2003).


Uk-100226-04 Southern side of Lake Awasa

Figure 2.58: Type Locality and Lithology of Shalo Lacustrine Deposits

e. Quaternary Sediments

Q Sediments

The description of this layer is in reference to the GSE (1994) Geology of the Agere Maryam Area.

Alluvium

Lithology : Fine sand and mud

Distribution : Each Lake and its surrounding area, Qe, Qa and lake deposits GSE (1994)

Thickness : 1 to 5 m

2.4 Correlation

Stratigraphy of above 6 areas in the Study was correlated and verified by respective articles, papers and chronology.

a. Stratigraphic correlation

Compared with the lithology of each unit and age by respective articles, correlative units of six areas are as follows.

Table 2.5: Correlation Chart of the Study Area

Period/ Epoch			Lake Ziway	Lake Abijata, Langano, Shala	Butajira- Hosaina	Lake Awasa	Sodo-Dila-YirgaChafe	Abaya-ArbaMinch	Major Lithology
Cenozoic	Quarternary	Holocene	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Fine sand - mud
			Bulbula lacustrine deposits	Bulbula lacustrine deposits		Shalo lacustrine deposits			Lake deposits such as gravel, sand and mud
			Mt. Aluto volcanics	Alge volcanics	Mt. Ambericho volcanics	Corbetti volcanics	Dugna Fango volcanics		Rhyolite lava flows, pumice falls, pumice flow deposits and Obsidian lava flows
			Deneba Recent Basalt	Awara Recent Basalt	Butajira Recent Basalt	Awasa Recent Basalt	Abaya Recent Basalts		Basalt lavas and reddish brown basaltic scoria
			Meki lacustrine deposits			Wondotika lacustrine deposits			Lake deposits such as poorly-sorted gravel, sand, pumice, tuff, and volcanic sand
		Pleistocene	Asela poorly welded pumiceous pyroclastics	Langano poorly welded pumiceous pyroclastics	Dugba poorly welded pumiceous pyroclastics	Shashemene poorly welded pumiceous pyroclastics			Yellowish white rhyolitic pumice tuff
			Kulmusa highly Welded-Tuff	Kuyera highly Welded-Tuff	Koshe highly Welded-Tuff	Mt. Kuwe highly Welded-Tuff	Samero highly Welded-Tuff		Rhyolitic to andesitic welded tuff
			Ketar river acidic volcano-sedimentary rocks	Lake Shala acidic volcano-sedimentary rocks	Amecho acidic volcano-sedimentary rocks	Yiega Alem acidic volcano-sedimentary rocks	Yirga Alem acidic volcano-sedimentary rocks	Post-rift Volcanics	Rhyolitic tuffs and pumice tuffs
			Gonde Strongly Green Welded-Tuff	Bilate river Strongly Green Welded-Tuff	Bilate river Strongly Green Welded-Tuff	Hantate Strongly Green Welded-Tuff	Hantate Strongly Green Welded-Tuff		Rhyolitic to andesitic welded tuff
			Adami Tulu basaltic pyroclastics	Shala Senbete basaltic pyroclastics		Abaye ridge basaltic pyroclastics	Donga basaltic pyroclastics		Basaltic tuff breccias and lapilli tuffs
			Ogolche Basalt	Lepis Basalt	Deneba Basalt	Yubo Basalt	Kebado Basalt		Massive basalt lavas
			Lekansho Lake deposits						Lake deposits such as gravel, sand and mud
	Neogene	Plio-Pleistocene	Gademotta rhyolite	Aje rhyolite	Gademotta rhyolite	Wendo Genet Rhyolite	Hobicha rhyolite	Gocho Rhyolite	Rhyolite lava flows and rhyolitic tuffs
			Bofa Basalt						Basalt Lavas and pyroclastics
			Hangasu Rhyolite			Wijigra Rhyolite			Rhyolitic tuffs
		Pliocene		Munesa rhyolite					Plagioclase rhyolite tuff
		Miocene						Sharenga Rhyolite	Rhyolite piles and necks
							Middle Basalt	Middle Basalt	Porous basalt lavas
		Eocene-Oligocene					Shole Ignimbrite	Shole Ignimbrite	Densely-welded rhyolitic welded tuff
							Lower Basalt	Lower Basalt	Porphyritic basalt lavas
Mesozoic					Adigrat Sandstone Antaro Limestone				Sandstone, Shale and Limestone
Pre-Cambrian					Biotite Gneiss, Pegmatite		Biotite Gneiss	Gneiss, Biotite Metagranite	Biotite Gneiss, Granite and Pegmatite

b. Correlation with previous articles and papers

b.1 Correlation with WoldeGabriel et al. (1990)

Lithologic, stratigraphic and chronologic studies were done by WoldeGabriel et al. (1990) through investigating marginal area of MER. They generally classified Pliocene strata as Chilalo Trachytes, and Pleistocene-Holocene strata as Wonji Group. Wonji Group was defined as volcano-sedimentary rocks which are formed by the activity of WFB. Those strata are correlated with all the identified units of the Study.

b.2 Correlation with Halcrow (2008)

Geological map of Rift Valley Lakes basin, the entire study area was previously reviewed by Halcrow (2008). They compiled some geological maps made by GSE, and united the stratigraphy and lithology. The general idea is similar to that of WoldeGabriel et al. (1990). In addition, they carried out detailed classification of lithology. The stratigraphy and lithology complied by Halcrow (2008) are correlated to those of the Study as follows;

Table 2.6: Correlation with Halcrow (2008)

Period/Epoch		Lake Ziway	Lake Langano, Abijata, Shala	Lake Awasa	Halcrow (2008) Lithology	Halcrow (2008) Stratigraphy
Quaternary	Holocene	Alluvium	Alluvium	Alluvium		Wonji Group
		Bulbula lacustrine deposits	Bulbula lacustrine deposits	Shalo lacustrine deposits	Ql	
		Mt. Aluto volcanics	Alge volcanics	Corbetti volcanics	Qwo, Qwpu	
		Butajira Recent Basalt	Awara Recent Basalt	Awasa Recent Basalt	Qwa,Qwbh、Qwh、Qwbp	
		Meki lacustrine deposits		Wondotika lacustrine deposits	Ql	
	Pleistcene	Asela poorly welded pumiceous pyroclastics	Langano poorly welded pumiceous pyroclastics	Shashemene poorly welded pumiceous pyroclastics	Qdi, Ql	
		Kulmusa highly Welded-Tuff	Kuyera highly Welded-Tuff	Mt. Kuwe highly Welded-Tuff	Qdi, Ql, Qdp, Qws, Qwh, Qvs	
		Ketar river acidic volcano-sedimentary rocks	Lake Shala acidic volcano-sedimentary rocks	Yiega Alem acidic volcano-sedimentary rocks	Qdi, Ql, Qdp, Qws, Qwh, Qvs	
		Gonde Strongly Green Welded-Tuff	Bilate river Strongly Green Welded-Tuff	Hantate Strongly Green Welded-Tuff	N1_2n, Qdi, Qdp, Qwh, Qwdp	
		Adami Tulu basaltic pyroclastics	Shala Senbeta basaltic pyroclastics	Abaye ridge basaltic pyroclastics	Qwh, Qwdp, NQs	
		Ogolche Basalt	Lepis Basalt	Yubo Basalt	Qwh, NQs, Qwdp	
		Lekansho Lake deposits			Qwh	
Neogene	Plio–Pleistcene	Gademotta rhyolite	Aje rhyolite	Wendo Genet Rhyolite	Qwa, Ql, Qdi, N1_2n	Chilalo Trachytes
	Late Miocene to Pliocene	Bofa Basalt		Wijigra Rhyolite	N1_2n, NQs	

b.3 Correlation with EWTEC (2008) and Dainelli et al. (2001) in Lake Ziway and Butajira – Hosaina Area

Geology of Lake Ziway – Butajira area was investigated by EWTEC (2008) from a hydrogeological point of view. Based on field survey and test drillings they classified Pliocene strata as Nazareth Group, Pleistocene strata as Wonji Group. Furthermore, Pleistocene basalt, trachyte and rhyolite lavas and pyroclastic rocks with lacustrine deposits are classified as Dino Formation.

Geology from Lake Ziway to Shashemene was conducted by Dainelli et al. (2001). They carried out field survey and classified the strata based on lithology. They conducted a detailed study about lacustrine sediments in late Holocene, and classified into four deposition stages.

Table 2.7: Correlation with EWTEC (2008) and Dainelli et al. (2001)

Period/Epoch		This Study		EWTEC (2008)		Dainelli et al. (2001)
		Lake Ziway	Butajira - Hosaina	Stratigraphy	Classification	
Quaternary	Holocene	Alluvium	Alluvium		Qab	
		Bulbula lacustrine deposits			Qa/Qj	Shore sand and reworked pumice (Qb)/ Shore sand and reworked pumice of poorly preserved strandlines (Qs2)
		Mt. Aluto volcanics	Mt. Ambericho volcanics	Wonji Group	-	Alutu-Bericho rhyolitic lava flows, unwelded pumice fall and pantelleritic obsidian flow (Qω)
		Butajira Recent Basalt	Butajira Recent Basalt		Basalt of the Rift Floor (QwBh)	Wonji-Butajira basaltic lava flows and scoria cones (Qfl)
		Meki lacustrine deposits			Qa/Qj	Clay, diatomite, sand, shell beds and reworked pumice (Ql1)
	Pleistocene	Asela poorly welded pumiceous pyroclastics	Dugda poorly welded pumiceous pyroclastics		Dino Formation (Qdi)	Volcanites of the Plateux (Tτ)
		Kulmusa highly Welded-Tuff	Koshe highly Welded-Tuff			
		Ketar river acidic volcano-sedimentary rocks	Amecho acidic volcano-sedimentary rocks			Volcanites of the Plateux (Tτ)/ Rift Floor Ignimbrite (Pρ)
		Gonde Strongly Green Welded-Tuff	Bilate river Strongly Green Welded-Tuff			Volcanites of the Plateux (Tτ)
		Adami Tulu basaltic pyroclastics			Qwbp	Alutu-Bericho rhyolitic lava flows, unwelded pumice fall and pantelleritic obsidian flow (Qω)/Colluvial-alluvial gravel, sand, silt and pyroclastic (Qcg)
		Ogolche Basalt	Deneba Basalt			Undifferentiated colluvial- alluvial gravel, sand, silt and pyroclastic (Qu)
		Lekansho Lake deposits			Dino Formation (Qdi)	
Neogene	Plio-Pleistocene	Gademotta rhyolite	Gademotta rhyolite		Central Volcanics Complex (Qwa)	Gademotta-Balci alkaline and peralkaline rhyolitic lava flows and domes (Pα)/Alutu-Bericho rhyolitic lava flows, unwelded pumice fall and pantelleritic obsidian flow (Qω)
	Late Miocene-Pliocene	Bofa Basalt		Nazareth Group	Qwbp	Rift Floor Ignimbrite (Pρ)
		Hangasu Rhyolite			-	Volcanites of the Plateux (Tτ) / Rift Floor Ignimbrite (Pρ)
					NQs, N1-2ar, N1-2n	
	Middle- late Miocene			Anchar Basalts	N1n	
				Arba Guracha Silisics	N1ar	
Mesozoic			Adigrat Sandstone Antaro Limestone	-	TJ	Gneiss, sandstones, shales, marls. Limestones (BM)
Pre-Cambrian			Biotite Gneiss	-	Pe	

b.4 Correlation with Mohr et al. (1980) at Lake Shala area

Detailed stratigraphy, volcanology and chronology of Shala (O'a) caldera were investigated by Mohr et al. (1980). Compared with this study, stratigraphy of Holocene basalt and rhyolite (silicicas) is upside down. It is confirmed that Alge volcanics, correlated to Post-Caldera Silicicas, continues volcanic activities during Holocene age in this study. Probably rhyolitic and basaltic activity has occurred simultaneously since Holocene.

Table 2.8: Correlation with Mohr et al. (1980)

Period/Epoch		This study	Mohr et al. (1980) Stratigraphy	Mohr et al. (1980) K-Ar Dating
Quaternary	Holocene	Alluvium	Holocene Lacustrine Processes	-
		Bulbula lacustrine deposits		
		Alge volcanics	Post-Caldera Silicic Volcanism (Qr2)	-
		Awara Recent Basalt	Younger Basaltic Lavas and Dikes(Qb3)	-
	Pleistocene	Langano poorly welded pumiceous pyroclastics	Weally Welded Beige Ignimbrite (Qi5)	0.25±0.03My
		Kuyera highly Welded-Tuff	Strongly Welded Green Ignimbrite (Qi4)	0.23±0.03My 0.22±0.03My 0.18±0.03My
		Lake Shala acidic volcano-sedimentary rocks	Pumice (Qi3)	0.59±0.04My
		Bilate river Strongly Green Welded-Tuff	Rhyolitic Flows and Domes (Qr1/Qi1)	0.28±0.01My
		Shala Senbeta basaltic pyroclastics	-	-
		Lepis Basalt		
Neogene	Plio-Pleistocene	Aje rhyolite		

b.5 Correlation with GSE (2003) in Awasa area

Detailed hydrogeography and applied geology were investigated in Awasa catchment by GSE (2003). Correlation with this study is as follows.

Table 2.9: Correlation with GSE (2003)

Period/Epoch		This study	GSE (2003) Stratigraphy	GSE (2003) Lithology
Quaternary	Holocene	Alluvium		
		Shalo lacustrine deposits		Qls, Qla
		Corbetti volcanics	Basalts of the rift floor/ Central Volcanic Complex	Qwr, Qwa, Qwo, Qwpu, Qlib
		Awasa Recent Basalt	Basalts of the rift floor	Qwbp
		Wondotika lacustrine deposits	Dino Formation	Qla, Qvs
	Pleistocene	Shashemene poorly welded pumiceous pyroclastics		Qdi, Qws
		Mt. Kuwe highly Welded-Tuff		Qdi, Qws, Qvs
		Yiega Alem acidic volcano-sedimentary rocks		Qdi, Qdp, Qwt1, Qwt2, Qvs
		Hantate Strongly Green Welded-Tuff		Qdi, Qvs
		Abaye ridge basaltic pyroclastics		Qwt1,Qlib, Qwbp, Qvs
		Yubo Basalt		Qwb
Neogene	Plio-Pleistocene	Wendo Genet rhyolite		Qwt1, Qwt2, Qdi, Qwpu
	Late Miocene to Pliocene	Wijigra Rhyolite	Nazaret Group	N1_2n, NQs

b.6 Correlation with GSE (1994) and GSE (2007) in Abaya- Arba Minch area

Detailed geological investigations were conducted in Yabelo and Hagare-Mariam area by GSE (1994) and GSE (2007). Those results are referred to in the Study. Correlation with those results is as follows;

Table 2.10: Correlation with GSE (1994) and GSE (2007)

Period / Epoch			Abaya- Arba Minch	GSE (2007) Yabelo Area	GSE (1994) Agere Maryam Area	
Cenozoic	Quaternary	Holocene	Alluvium (Q /Al)	Quaternary Sediments (Qal, Qcf, Qel)	Quaternary Sediments (Qe, Qa, Q)	
		Pliestocene	Post-rift Volcanics (ba)	Post-rift Volcanics (QBb, Qvs, Qps, QGb)	Post-rift Volcanics (Qn, Qs, Qb, Qd, Qc)	Qn: 1.34My Qb: 0.68-0.99My
	Neogene	Plio-Pleistocene	Gocho Rhyolite (rh)			
		Miocene	Sharenga Rhyolite (Ngs)		Sharenga Rhyolite (Ngs)	13.0My
				Scoriaceous Basalt (Tsc)	Upper Basalt (Ngu)	
				Undifferenciated volcanic rocks (Tuv)	Beyana Tuff (Ngb)	
			Middle Basalt (Ngm)		Middle Basalt (Ngm)	11.1My 12.6-12.9My
		Eocene-Oligocene	Shole Ignimbrite (Pgs)		Shole Ignimbrite (Pgs)	35.5-37.0My 33.9My
			Lower Basalt (Pgl)	Olivine phylic Basalt (Tob)	Lower Basalt (Pgl)	36.7-37.9My 37.6-44.9My
					Arba Minch Felsic Tuff (Pga)	
					Pre-rift basal red sandstone (Pgr)	
Pre-Cambrian			Gneiss, Biotite Metagranite (Pre)	Gneiss, Amphibolites, Schists, Granotoids	Gneiss, Granurite, Granotoids	

2.5 Chronology (K-Ar age Method)

2.5.1 Purpose of age determination

The objective of this dating for the rocks is to confirm the correlation and age of welded tuff. There was no plan initially for the dating of rock samples. However, as a result of geological field survey, the strata were fractionized by the key bed of welded tuff comparing to the existing geological map, and the correlation of strata was done in each area. This is the methodology of the correlation with lithology and by the combination of strata. The correlation of each layer is no problem in the range of field survey. However, it is better to confirm that there are no discrepancies of stratigraphy and to comprehend the distribution of strata adequately by dating.

2.5.2 Methodology of dating

The age determination is the K-Ar age method by the mineral detachment (Feldspar), quantitative analysis for Kalium, and Ar isotopic ratio dating.

2.5.3 Sampling points and startigraphy

The sample points and stratigraphy are as followg in Table 2.11.

Table 2.11: Stratigraphy of sample

Period/Epoch		Lake Ziway	Lake Langano, Abijata, Shala	Lake Awasa	Purpose	Quantity of sp	Method	Estimated Age
Quaternary	Holocene	Alluvium	Alluvium	Alluvium				
		Bulbula lacustrine deposits	Bulbula lacustrine deposits	Shalo lacustrine deposits				
		Mt. Aluto volcanics	Alge volcanics	Corbetti volcanics				
		Butajira Recent Basalt	Awara Recent Basalt	Awasa Recent Basalt				
		Meki lacustrine deposits		Wondotika lacustrine deposits				
	Pleistcene	Asela poorly welded pumiceous pyroclastics	Langano poorly welded pumiceous pyroclastics	Shashemene poorly welded pumiceous pyroclastics				
		Kulmusa highly Welded-Tuff	Kuyera highly Welded-Tuff	Mt. Kuwe highly Welded-Tuff	Correlation of Welded Tuff	5area X1sp=5sps	Feldspar disatachment +Ar second times	<1.0Ma
		Ketar river acidic volcano-sedimentary rocks	Lake Shala acidic volcano-sedimentary rocks	Yiega Alem acidic volcano-sedimentary rocks				
		Gonde Strongly Green Welded-Tuff	Bilate river Strongly Green Welded-Tuff	Hantate Strongly Green Welded-Tuff	Correlation of Welded Tuff	5area X1sp=5sps	Feldspar disatachment +Ar second times	<1.0Ma
		Adami Tulu basaltic pyroclastics	Shala Senbete basaltic pyroclastics	Abaye ridge basaltic pyroclastics				
		Ogolche Basalt	Lake Chitu Basalt	Yubo Basalt				
		Lekansho Lake deposits						
Neogene	Plio-Pleistcene	Gademotta rhyolite	Aje rhyolite	Wendo Genet Rhyolite				
	Late Miocene to Pliocene	Bofa Basalt	Lepis Basalt					

Table 2.12: Sample points

No.	Unit Name	Sample Location	Coordination	
			WGS 84	UTM (*1)
1	Koshe highly Welded-Tuff	Kibet, south of Butajira	8^0 00' 11.62"N 38^0 19' 15.52"E	0884510 0425079
2	Kulmusa highly Welded-Tuff	Ziway – Asela roadside	8^0 04' 21.79"N 39^0 08' 33.52"E	0892133 0515624
3	Kuyera highly Welded-Tuff	Quarry in Kuyera	7^0 17' 03.24"N 38^0 39' 18.00"E	0804978 0461825
4	Mt. Kuwe highly Welded-Tuff	Mt. Kuwe, south of Awassa	6^0 58' 20.05"N 38^0 24' 23.06"E	0770514 0434339
5	Samero highly Welded-Tuff	Warem, west of Dilla	6^0 24' 31.91"N 38^0 15' 57.86"E	0708253 0418744
6	Gonde Strongly Green Welded-Tuff	Ziway – Asela roadside	7^0 59' 52.58"N 39^0 05' 30.82"E	0883864 0510034
7	Bilate river Strongly Green Welded-Tuff	Eastern side of Lake Shala	7^0 27' 23.82"N 38^0 38' 33.60"E	0824036 0460479
8	Bilate river Strongly Green Welded-Tuff	Kulito(Sodo-Shashemene roadside, along Bilate Riv.)	7^0 17' 15.51"N 38^0 04' 25.02"E	0805445 0397647
9	Hantate Strongly Green Welded-Tuff	Hantate, south of Awassa	6^0 42' 14.29"N 38^0 15' 06.96"E	0740880 0417229
10	Hantate Strongly Green Welded-Tuff	Warem, west of Dilla	6^0 25' 26.34"N 38^0 16' 56.25"E	0709922 0420540

2.5.4 Results

The results of dating are as follows;

Table 2.13: K-Ar Age

Sample name	Materials (Mesh size)	K Content (wt.%)	Radioactivity-origin40Ar (10^{-8}cc STP/g)	K-Ar Age (Ma)	Non Radioactivity-origin40Ar (%)
UK110122-01SP01	Feldspar (#100-200)	4.073 ± 0.081	20.09 ± 0.56	1.27 ± 0.04	57.3
UK110129-01SP02	Feldspar (#100-200)	4.604 ± 0.092	4.71 ± 0.68	0.26 ± 0.04	89.9
UK110126-01SP03	Feldspar (#100-150)	5.216 ± 0.104	4.34 ± 0.28	0.21 ± 0.01	78.1
UK110128-01SP04	Feldspar (#100-150)	4.516 ± 0.090	22.43 ± 0.40	1.28 ± 0.03	38.6
UK110124-02SP05	Feldspar (#100-200)	4.704 ± 0.094	543.8 ± 5.3	29.55 ± 0.65	3.0
UK110129-02SP06	Feldspar (#100-200)	4.216 ± 0.084	3.57 ± 0.58	0.22 ± 0.04	91.0
UK110127-01SP07	Feldspar (#100-200)	3.418 ± 0.068	17.96 ± 0.61	1.35 ± 0.05	63.5
UK110125-01SP08	Feldspar (#100-200)	5.106 ± 0.102	3.78 ± 0.30	0.19 ± 0.02	82.4
UK110124-03SP09	Feldspar (#100-200)	5.745 ± 0.115	52.08 ± 0.62	2.33 ± 0.05	18.1
UK110124-01SP10	Feldspar (#100-200)	4.997 ± 0.100	17.67 ± 0.45	0.91 ± 0.03	54.0

a. Discussion

Prior to the age determination, the simple observation of thin section of the rock samples was curried out under the microscope at Hiruzan Chronology Laboratory in Japan and also the microscope observation was also executed in Shinshu University in Japan. The age of two successive layers in this dating has a high probability to take a range of 0.2-0.3 Ma based on the existing data (refer to the age stratigraphy correlation chart of annex). However, as the results of dating, the half samples indicated more than 1 Ma of K-Ar age. So the results of dating were discussed for the believability for age of rocks as below.

SP1: Feldspar was not reset because of low welded conditions. And feldspars (Sanidine) are fresh, but there are lots of lithic fragments, the sanidine from the lithic fragments are mixed in, and it is possible that this makes the age older. Moreover, accidental materials of Gedemotta rhyolite (1.27-1.28My) are also probably mixed in. The relationship of stratigraphy is clear.

SP2: The welded condition is high, and the feldspars (Sanidine) are fresh. The lithic fragments are rich, but sanidine is not mixed in the lithic fragments. The relationship of stratigraphy is clear.

SP3: The welded condition is high, and the feldspars (Sanidine) are fresh. The lithic fragments are rich, but sanidine is not mixed in the lithic fragments. The relationship of stratigraphy is clear.

SP4: The welded condition is high, the feldspar is metamorphosed and the lithic fragments are rich. As the feldspars (Anorthoclases) are mixed in the lithic fragments, it is possible this makes the age older. Moreover, accidental materials of Abya ridge basaltic pyroclastics (1.27±0.1My) are also probably mixed in. The relationship of stratigraphy is clear.

SP5: The welded condition is high, although the feldspars (Sanidine) are contained in the lithic fragments, the lithic fragments are poor. This sample point is located in the southern most area, it is possible to classify by the rhyolitic welded tuff (Shole Welded Tuff) distributed below this sample. It needs to change the geological distribution.

SP6: The metamorphosis level of the feldspar is low, and the welded condition is high. The sanidines are not mixed in the lithic fragments. The relationship of stratigraphy is clear.

SP7: The welded condition is not so high (microscope observation prior to dating). Feldspar was probably not reset. As the feldspars (Anorthoclases) are possibly mixed in the accidental materials, it is possible this makes its age older. Moreover, accidental materials of Sala senbete basaltic pyrocrastics correlated with Abya ridge basaltic pyroclastics (1.27±0.1My) are also probably mixed in. The relationship of stratigraphy is clear

SP8: The feldspar (Sanidine) is metamorphosed slightly, and the welded condition is high. The lithic fragments are poor, and sanidine is not mixed in the lithic fragments. The relationship of stratigraphy is clear.

SP9: The welded condition is not so high (microscope observation prior to dating). Feldspar was not reset probably. The accidental materials of Wendo Genet Rhyolite (2.49±

0.1My) are probably mixed in. The relationship of stratigraphy is clear.

SP10: As the feldspars (Sanidine) in the lithic fragments are possibly mixed, it is possible that this makes the age older. Moreover, accidental materials of Donga basaltic pyrocrastics correlated with Abya ridge basaltic pyroclastics (1.27±0.1My) are also probably mixed in. The relationship of stratigraphy is clear

The chronological values (0.19±0.03Ma-0.26±0.04Ma) of the four of ten samples is consistent with the past ages, and it is possible to correlate the dating age from along the Bilate river to Asela area and the results of dating are also consistent with the stratigraphy of the field in the north area of Lake Awasa. SP05 sampled in the southernmost area of six remaining samples is similar to the lithology of Highly Welded Tuff. The reason why the SP05 was sampled is to confirm the distribution of Highly Welded Tuff in the surrounding area. As the resalts of dating, SP05 was dated by 29.55±0.65Ma and could also get credibility for the chronological values of sample under microscope observation. Consequently the sample of SP05 correlates with the Shole Welded Tuff distributed below Highly Welded Tuff. Therefore, it is possible that the Strongly Welded Tuff and Highly Welded Tuff which was dated age in this time are not distributed south of Dila, and can be corroborated from the results of dating.

2.6 Geological structure

2.6.1 Fault systems

a. General

NNE-SSW fault systems are developing at the margin and rift floor in RVLB. The degree of development is slightly different between the northern and southern parts.

Fault system in northern RVLB is characterized by the development of continuous major faults which has big displacement with minor parallel faults, and fault zones associated with volcanic activity in the rift floor. While, Pre-Cambrian and Neogene fault system in southern RVLB is neither continuous nor regular.

The difference of the development of those faults is deeply related with the development of basin in RVLB, it indicates that the basin is well developed in the northern part and poorly developed in the southern part.

WoldeGabriel et al., (1990) classified the distribution of those faults and considered that Rift Valley Marginal Faults were active at the formation of the valley and are still active. Furthermore, with the development of RVLB, spread of rift floor has been started through the development of Wonji Fault Belts since Pleistocene age.

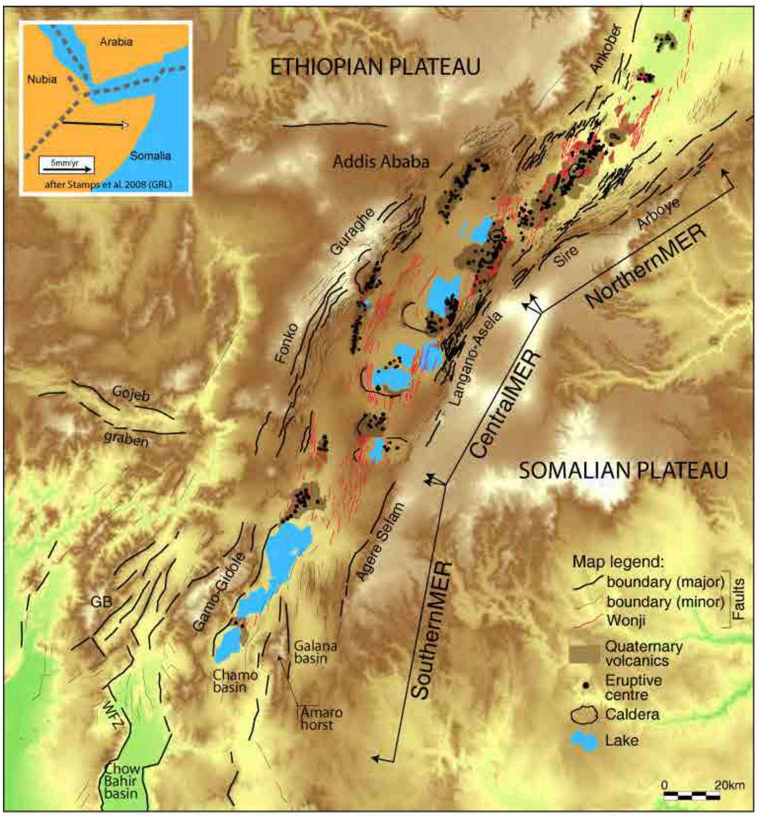


Figure 2.59: Distribution of Fault Systems in Ethiopian Rift Valley Region
(Source: http://www.mna.it/MER/history.htm)

b. Pre-Cambrian to Eocene Fault System

Pre-Cambrian, Eocene and Oligocene formation is distributed from the south of Lake Abaya.

NE-SW and perpendicular NNW-SSE fault systems are observed at that area, however the faults are distinctive. NE-SW faults form half-graben structures and Quaternary talus and alluvial deposits are distributed in the half-grabens.

c. Miocene to Pliocene Fault System

N-S fault system is deforming Oligocene to Eocene basalts and rhyolites in Yirga Chafe, the south of Dila, partially forms half-graben. These faults are unclear and distinctive in Hagare Mariam.

The major direction of above fault system in this area is slightly different as that in Quaternary, furthermore displacement of those faults in Quaternary are not clear. Thus it is concluded that those faults might be developed when RVLB was formed.

d. Plio-Pliestocene to Holocene Fault System

NNE-SSW fault system is developed at the margin and basin floor in RVLB. Especially, marginal fault system is characterized by the combination of continuous major faults which has big displacement and minor fault groups which has small displacement and distinctive.

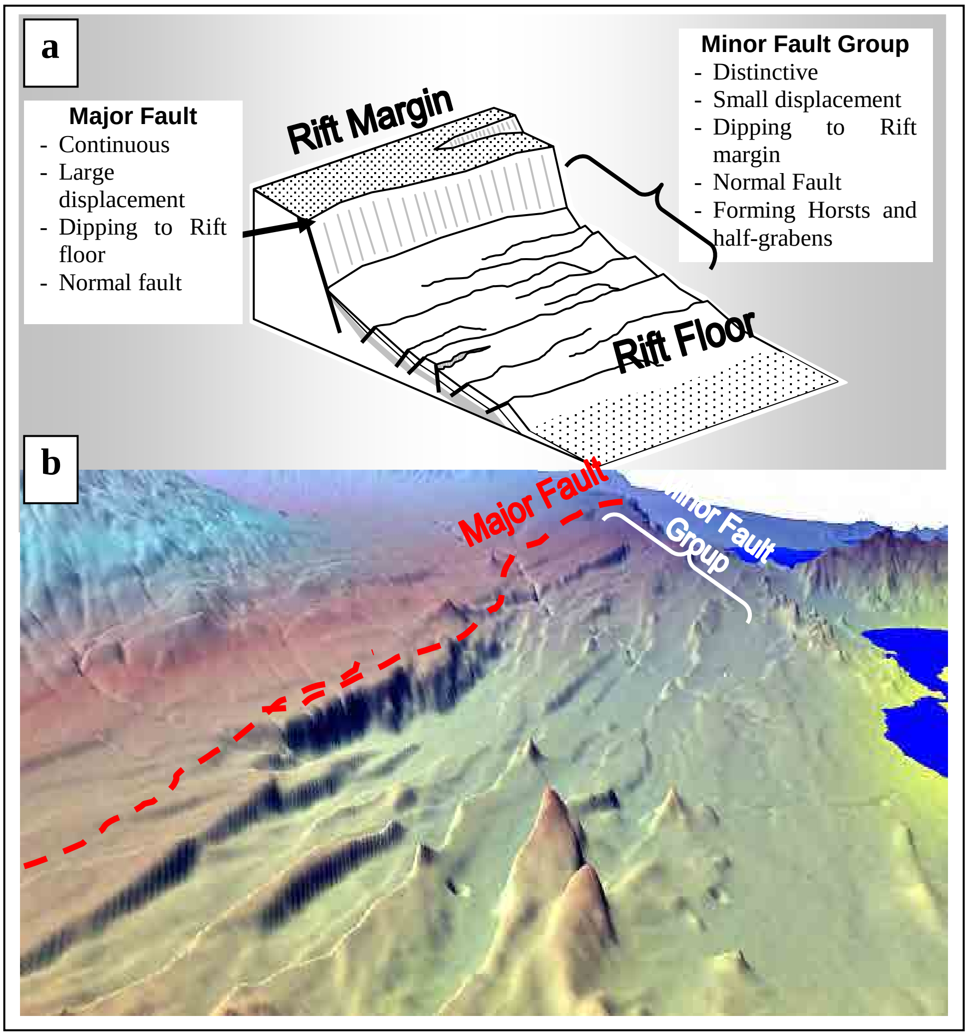


Figure 2.60: (a) General Fault structure in Marginal fault system in northern RVLB
(b) 3-dimentional view in Asela-Langano area (toward to the south)

Such a combination is commonly observed at the eastern margin from Asela to the east of Lake Langano and western margin from Butajira to Hosaina. In the south of Awasa, marginal fault system is composed only of minor fault group without continuous major fault.

2.6.2 Neo-tectonics

Active ground cracks are observed and reported in RVLB. In this study, ground cracks are found at the east and south of Lake Shala, western part of Awasa basin (Awasa caldera).

In Awassa area, Lake Derba, located at the western part of Awassa basin, dried up due to the formation of ground cracks in the late 1980's. Lake water penetrated into the cracks and might have discharged to Lake Awassa, so it might be a significant factor in the rising water level of Lake Awassa nowadays (T.Ayenaw: Natural Lakes of Ethiopia, 113P).

Those ground cracks are concordant with Wonji Fault Belt and distribution of recent basalt units defined in this Study, considered to be phenomena of recent spreading axis of RVLB.

Ground cracks in west part of Awassa (Ho-100421-02)	Huge ground cracks in east of Lake Shala (Uk-100226-07)

Figure 2.61: Ground Cracks

2.7 Volcanic activities

2.7.1 Distribution of volcanoes in RVLB

WoldeGariel et al. (1990) summarized the history of volcanic activity and its distribution. According to that study, large calderas by rhyolitic rocks and volcanic lines composed of single volcanic cones by basaltic rocks are observed in RVLB. In this Study, distribution of volcanoes and calderas are recognized by satellite imagery. Those volcanoes are marked in 1:250,000 geological maps in this Study.

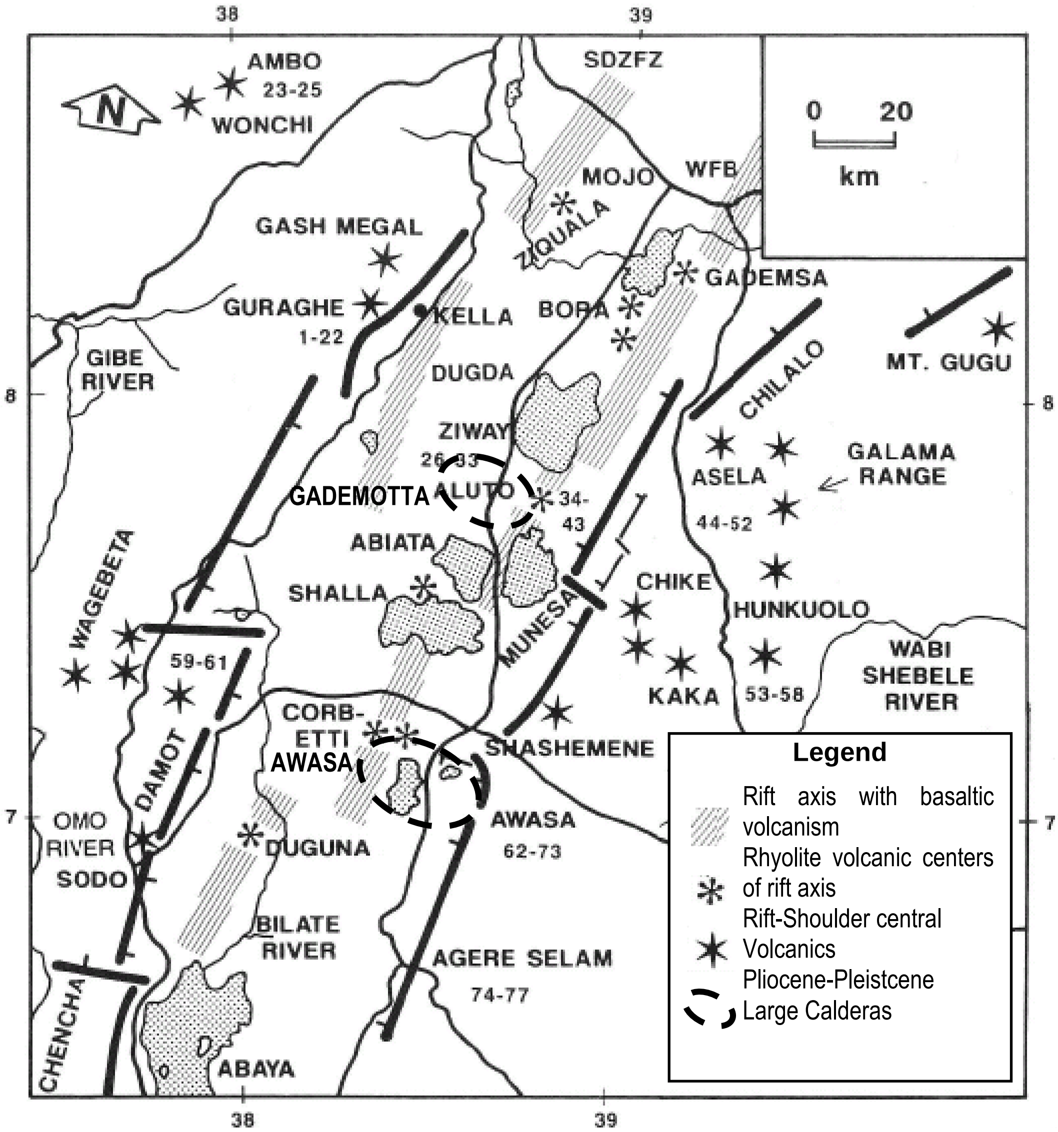


Figure 2.62: Distribution of Volcanoes in Central MER (modified by WoldeGabriel et al. 1990)

2.7.2 Characteristics of volcanoes in RVLB

Recent volcanoes distributed in RVLB were formed by the development of WFB trending NNE-SSW, which has been formed since late Pliocene. The activity of WFB is associated with bimodal volcanic activities of basalts and rhyolites. These volcanics are classified as alkalic rocks which are rich in Na_2O and K_2O.

a. Volcanic Activity in late Pliocene to early Pleistocene stage

a.1 Basaltic activity

Basaltic rocks in this stage are as follows; Bofa Basalt, Ogolche Basalt and Adami Tulu basaltic pyroclastics in Lake Ziway area, Lepis Basalt and Shala Senbete basaltic pyroclastics in Abijata-Langano-Shala area, Yubo Basalt and Abaye ridge basaltic pyroclastics in Awasa area. It is difficult to ascertain the thickness or distribution of the aforementioned basaltic rocks because of a lack of outcrops. Abaye ridge basaltic pyroclastics, which is observed at the west of Awasa, shows NNE-SSW distribution thus the activity was specific and formed volcanic belts toward WFB. Bofa basalt, which is observed at the southwest of Lake Ziway, is distributed at the depth from GL-600m to GL-1300m, indicates that basalts are thickly deposited along the volcanic belt.

Those basaltic rocks consist of basalt lavas and thick basaltic pyroclastics which show subaqueous volcanism. It may indicate that gigantic or many lakes covered RVLB in this stage.

a.2 Rhyolitic activity

Rhyolitic activity formed huge mountain body and calderas in this stage, it is believed from recent topographic features. Major calderas formed in this stage are as follows;

Table 2.14: Rhyolitic activity in late Pliocene to early Pleistocene stage

Caldera Name	Size	Depth	Estimated Volume	Age of Activity	Age of Depression
Gademotta	14 x 28km	300m	94km^3	1.3Ma(1)	1.1Ma(1)
Awasa	22 x 38km	300m	200km^3	2.5-1.1Ma(1)	0.2Ma(1)

(1) WoldeGabriel et al. (1990)

Deposition of thick pyroclastics is related directly or indirectly to calderas and most researchers believe that they were erupted from ring fractures concomitant from caldera collapse. On the other hand, collapse of a Plinian eruption column produces pyroclastics (R.V.Fisher and H.-U.Schminske 1984).

a.2.1 Gademotta caldera

Gademotta caldera is located 130km to the south of Addis Ababa. Now, only the western caldera wall is remaining, and eastern wall was buried by subsidence of rift floor (WoldeGabriel et al.1990, Le Turdu et al. 1999). NW-SE gap in the thickness of rhyolitic pyroclastics found in boreholes in Mt. Aluto, is believed to be the buried wall of Gademotta caldera (GSE, 1986). Based on respective data, a 28km long, 14km wide ellipsoidal caldera wall is estimated.

Thick and extensive rhyolite lava flow is observed on the western wall of Gademotta caldera, which is defined as Gademotta rhyolite in the Study. River sediments overlying the rhyolite lava show a flow direction from east to west and intercalate small rhyolite lava associated with obsidian chilled margin. This indicates that the sediments were supplied from the volcano body before the formation of caldera. Thick pumice tuff covered concordant with surface and no welded tuff was found at the caldera wall, therefore, it is concluded that the volcanic activity of Gademotta caldera is characterized by the eruption of rhyolite lavas and pumice. The entire volume of lavas and pyroclastics are estimated at 94km^3

Adami Tulu basaltic pyroclastics overlying the rhyolite by unconformity at the caldera wall indicates that basaltic activity may have started after the rhyolite activity and before the formation of the caldera.

The age of Gademotta rhyolite exposed at caldera wall is 1.30±0.1My (WoldeGabriel et al. 1990) and basalts overlying rhyolite is 1.16-1.97My (WoldeGabriel et al. 1990, from Ogorche basalt). Formation of the caldera may be younger than 1.1Ma based on those respective data.

a.2.2 Awasa Caldera

Awasa caldera is located at 210km south from Addis Ababa. The caldera wall is still remaining and northern part of caldera wall was replaced by Corbetti volcanics. Its size is estimated to be 38km in length, and an ellipsoidal width of the caldera wall of 22km.

Thick and extensive rhyolite lava flow is observed at the northern wall of Awasa caldera, which is defined as Wendo Genet rhyolite in the Study. At the western wall, Wondotica lacusturine deposits overlie Wendo Genet rhyolite by unconformity, and Abaye ridge basaltic pyroclastics overlies Wondotica lacusturine deposits by unconformity. At the southern wall, Hantate green strongly welded tuff and Mt. Kuwe highly welded tuff are observed at very limited part and thick pumice tuff covered concordant with surface to the south. Therefore, it is concluded that the volcanic activity of Awasa caldera is characterized by the eruption of rhyolite lavas, pumice and formation of welded tuffs. The entire volume of lavas and pyroclastics are estimated as 200km^3

Yubo basalt and Abaye ridge basaltic pyroclastics overlie rhyolite by unconformity at the caldera wall indicates that basaltic activity may have started after rhyolite activity before the formation of the caldera.

The age of Wendo Genet rhyolite is 2.49±0.1My at Boricha Ridge (WoldeGabriel et al. 1990) and rhyolitic welded tuff exposed at upper part of eastern wall is 1.1-1.85My (WoldeGabriel et al. 1990). Furthermore, Hantate green strongly welded tuff is 0.21My at the bank of Bilate River, 40km northwest of Awasa. Formation of caldera might be younger than 0.2Ma based on those respective data.

b. Volcanic Activity in middle Pleistocene to recent stage

b.1 Basaltic Activity

Basaltic rocks in this stage are as follows; Butajira Recent Basalt in Lake Ziway area, Awara Recent Basalt in Abijata-Langano-Shala area, Awasa Recent Basalt in Awasa area. Basaltic rocks of this stage forms volcanic belts along WFB, fissure eruptions may have been caused by faults or deep tension cracks. The basaltic units generally form scoria cones and sometimes form maar. Distribution areas of Awara Recent Basalt at the southwestern side of Lake Shala, NNE-SSW cracks are being formed at the ground. Above all, basaltic volcanic belts are tension axis of recent MER (WoldeGabriel et al.1990).

b.2 Rhyolitic Activity

Rhyolite activity is located on the basaltic volcanic belt and forms volcanic bodies and partly associating caldera. Rhyolitic volcanoes are called from the north; Aluto, Shala (caldera), Corbetti and Dugna. In Butajira area there are no rhyolitic volcanoes, nor have there been any eruptions. Major rhyolitic volcanoes formed in this stage are as follows;

Table 2.15: Rhyolitic activity in middle Pleistocene to recent stage

Name	Size	Height (Depth)	Volume	Age of Activity	Recent activity
Aluto	10x 12km	250m	8km^3	0.27-0.021Ma(4)	Fumarole
Shala	15 x 16km	500m(2)	96km^3	0.28-0.18Ma(3)	-
Corbetti	7 x 8km x 2	600m	18km^3	0.02Ma(1)	Fumarole
Dugna	13 x 14km	600m	29km^3	---	-

References : (1) WoldeGabriel et al. 1990, (2) Le Turdu et al. 1999, (3) :Mohr 1980, (4) Laury and Albritton, 1975

b.2.1 Aluto Volcano

Aluto volcano is located 130km south of Addis Ababa between Lake Ziway and Lake Langano. Diameter of volcano is around 10km and height is around 250m from the foot. A small ellipsoidal-shape depression of 3.5x2km exists on the mountain, thus, the volcano has formed a caldera. Recently Fumarole is still available at the southern part of the volcano.

Geology of Aluto volcano is classified as Mt. Aluto volcanics in the Study, overlies Bofa Basalt by unconformity from some borehole data. Furthermore, the stratigraphic gap was found at borehole data, and it is believed to be the buried wall of Gademotta caldera (GSE 1986). Aluto volcano might be located on the margin of Gademotta caldera.

A small rhyolitic pumice flow deposit and obsidian lava was observed in the Study. The age of Mt. Aluto volcanics shows broad range of 0.27-0.021Ma (Laury and Albritton, 1975). The volcano is developed in Holocene age, but the volcanic activity began in the middle Pleistocene.

b.2.2 Shala Caldera

Shala caldera is located 170km south of Addis Ababa, the caldera is known as Lake Shala. The diameter of caldera is around 15-16km and the deepest point of the lake is around 250m (Le Turdu et al, 1999), the total height of caldera wall is 500m. Bilate River Green Strongly Welded Tuff is observed at the foot of eastern cliff, and Kuyera highly Welded Tuff is exposed at the top. Lake Shala acidic volcano sedimentary rocks were erupted from Shala volcano, because the maximum thickness is at the caldera wall, at around 150m (Mohr et al. 1980).

Kuyera highly Welded Tuff and Langano poorly welded pumiceous pyroclastics were also erupted from Shala volcano (Mohr et al. 1980). The result of investigation of the Study, Langano poorly welded pumiceous pyroclastics has maximum thickness at the western side of Lake Langano and it may have been erupted from Shala volcano.

The Age of 0.28Ma from Bilate River Green Strongly Welded Tuff (WoldeGabriel et al.1990), 0.23-0.18Ma from Kuyera highly Welded Tuff at uppermost part of caldera wall, and 0.25Ma from Langano poorly welded pumiceous pyroclastics (Mohr et al. 1980) is reported at Shala volcano.

b.2.3 Corbetti Volcano

Corbetti volcano is located at 15km north from Awasa, SNNPRS. The volcano consists of some volcanic bodies, generally classified into two units; Mt.Urzi (EL.2189m) and Mt. Chebi (EL.2314m). Caldera wall is developing at the southern and western foot of Corbetti volcano.

Both volcanic bodies have a vent at the top, and consist of obsidian lava and pumice fall deposit by Plinian eruption. Pumice fall may have erupted from Mt. Urzi and widely distributed surrounding Corbetti volcano; 1.5m thick on the roadside of Awasa-Shashemene route, 12km to the east of the volcano and 1.0m thick at Aje, 14km to the west of the volcano.

Early Holocene Wondotica lacustrine deposits overlies Wendo Genet Rhyolite at the southern caldera wall, therefore, the formation of the caldera might be younger than early Holocene. Age of 0.02 Ma from obsidian lava at the foot of Mt.Chebi (WoldeGabriel et al.1990) supports this expectation.